SCIENCE

An Introductory Text book

E. J. HOLMYARD

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SCIENCE

AN INTRODUCTORY TEXTBOOK

SIR RONALD ROSS

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By

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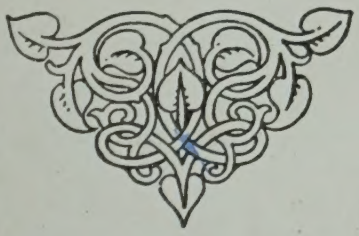

"All things . . . . . to each other linkéd are."

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PREFACE

THIS little book is an attempt to present science as a whole to young students. No division of the work into the usual water-tight compartments has been made, and reference has been made throughout to phenomena of everyday life. The difficulty of teaching General Science has been, I believe, mainly due to the fact that too much was attempted. Teachers have not courageously recognised that in an elementary course on General Science many things must perforce be omitted, and the consequence has been that the average scheme degenerates into a collection of snippets from chemistry, physics and biology. I do not hope to have overcome these difficulties altogether, but I have tried to surmount them by taking the four Aristotelian elements as the framework of my scheme. A short treatment of biological subjects has followed naturally.

The greater portion of the course described has been in use for some years at Clifton College, for the most part with gratifying success. I hope that its publication may assist other teachers who have to face the problem of how best to teach Elementary Science, and I should be most grateful for any criticisms and suggestions which readers may be good enough to send.

I have to express my thanks to the following gentlemen for permission to use certain drawings: Mr. H. J. Shepstone, F.R.G.S., for the drawing of the electro-magnet on p. 156; the Encyclopædia Britannica Co., Ltd., for the drawings mentioned in the text; Messrs. Macmillan and Co., Ltd., for the use of drawings from Parker's *Elementary Course*

of Practical Zoology; the British Oxygen Co., Ltd., for the block of the Liquid Air Plant on p. 34; Messrs. G. Newnes and Co., Ltd., for the drawings of the Amœba and Hydra, from the *Outline of Science*; and Messrs. Edward Arnold and Co. for the drawing showing how a liquid air plant works. Several drawings in the biological section have been based upon and modified from Lowson's *Text-Book of Botany*, published by the University Tutorial Press.

E. J. HOLMYARD.

CLIFTON COLLEGE, BRISTOL,
26 *March*, 1926.

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SCIENCE

CHAPTER I

THE STORY OF SCIENCE

What is Science?—Since one of the objects of this book is to encourage you to ask questions, you cannot be blamed if you begin at once by asking, "What is Science?" It is only natural that you should want to know exactly what you have to grapple with, so let us try to get some idea of it before we cast off the hawser and set sail. Many learned men have written many learned books in order to explain precisely what they meant by "science," but we shall not be far from the truth if we look upon science as man's attempt to find out how the world works and what it and all the things in it are made of. This curiosity is by no means a modern growth. Ever since man began to think at all he has been asking himself questions about Nature, though we shall see later on that nowadays we are more modest in our questioning than were some of the ancient wise men, and instead of asking *ourselves* the questions we put them to Nature and humbly await her answer.

Why do we study Science?—Perhaps the second query you will make is, "*Why* do we want to know all about the world?" There are two answers to this. In the first place we want to know simply through sheer curiosity. That instinct which makes us long to know other people's business (which is, after all, often far more interesting than our own) will not let us rest quietly before the fascinating problems which lie all around us. Man has an unquenchable thirst for knowledge merely for the pleasure of knowing,

and since this is a basic fact of human nature we just have to admit that it is so and leave it at that.

The second answer to the question is, that we desire to know as much as possible about Nature in order to make our lives more comfortable and less dangerous. The more control we have over fire, air, earth and water, over plant and animal life, and over our own bodies, the more we shall be able to improve the lot of our fellow-men and of ourselves. In a thunderstorm, electricity is a foe which may strike us unawares at any moment; made in a dynamo and sent along wires to all parts of a big city it is a willing and untiring slave, capable of working more wonders than the Jinn in the *Arabian Nights*.

We see, therefore, that we study science because we are curious to know and also because the knowledge we so obtain is of practical value. Now, in early days, life was far too strenuous and exciting to allow men much time in which to get knowledge simply for the sake of knowledge. When it is difficult to guess where one's next meal is coming from, and enemies are likely to be lurking behind every convenient boulder, only a very exceptional man would use his flint axe to draw right-angled triangles in the sand, in order to discover something about the square on the hypotenuse. Ancient men therefore aimed chiefly at getting knowledge which should be of immediate practical value, and, in addition, they tried to get that knowledge by short cuts. It is not surprising that they generally completely failed and often made the most foolish mistakes. What is surprising is the number of times they were right. As an example of the methods they used, we may suppose that, on one occasion, before going into battle, the chief of a tribe noticed that a black dog with a white ear barked three times. If that tribe came out of the conflict victorious, the chances are that the chief would imagine his victory to be due partly to the dog, and before going into battle again he would certainly try to

procure a similar dog and make it bark the same number of times.

In the same kind of way the ancient Egyptians, having been impressed by the green colour of the young corn growing vigorously by the banks of the Nile after the yearly flood, came to the conclusion that if they painted themselves with a green paint they also would be young and vigorous. Again, since the sun is necessary to life, they imagined that gold, which is of the same colour, must also have life-giving powers, and so they searched far and wide for this precious metal in order that it might give them health and strength when they wore it.

Ancient Egyptian Science and Magic.—In spite of these and similar beliefs, which at the present day we look upon as very foolish, the Egyptians managed to acquire a great deal of knowledge of a much more solid kind. Not only did they discover many facts which are of vast importance even to-day: they invented several habits which have lived through the centuries and are still to be found among us. Many men of science, in fact, believe that all the different civilisations of the world, if traced back far enough, can be shown to have descended directly from that of Egypt

Professor Elliot Smith tells us that the Egyptians invented agriculture, carpentry and the art of building.

> They seem also [he says] to have been the inventors of linen and of the craft of weaving, of the use of gold and copper, and the making of metal tools and implements. They were the first people to measure the year and to devise a calendar. . . . They also invented shipbuilding and constructed the first sea-going ships. . . . The art of shaving, the use of wigs, the wearing of hats, the invention of the kilt and of the sandal, and subsequently of a variety of other articles of dress, many of our musical instruments, chairs and beds, cushions, jewellery and jewel-cases, lamps—these are merely a few of the items picked at random out of our ancient heritage from the Nile valley.

For the measurement of the year and the construction of a calendar the Egyptians must have observed the movements of the sun and stars very closely, and in this way that branch of science which we call astronomy was begun. Many of the arts and crafts in which the Egyptians excelled required a good deal of knowledge which we should now describe as "scientific." Thus a department of science which is of very great importance in the modern world, *chemistry*, first saw the light in the attempts of the Egyptians to purify gold and silver and to extract other metals from their ores. Since the metals play such a vital part in present-day civilisation, it will be interesting to inquire a little more closely into this matter and to find out exactly what the ancient dwellers by the Nile knew about metals and metal-working.

Of all the metals, that which we should find it most difficult to do without is iron. Now, although iron ores exist in enormous quantities, it is by no means an easy matter to get the metal from these ores. Yet a piece of iron has been discovered in the masonry of the great pyramid built by the Pharaoh Cheops (about 2500 B.C.), and from ancient wall-paintings we can see the actual methods which the Egyptians used in iron-smelting.

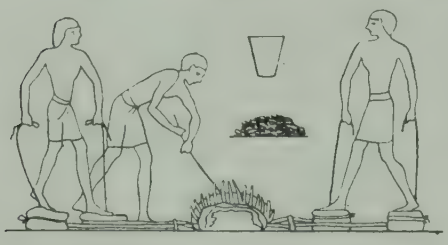


FIG. 1. ANCIENT EGYPTIANS SMELTING IRON

The figure shows two labourers working foot-bellows which blow air into a charcoal-fire containing iron-ore. Bellows of a similar kind are still in use in various parts of Central Africa.

The metals known to the Egyptians were gold, silver, copper, iron and lead. In addition to these, many other minerals were frequently employed, such as mica, turquoise and a bluish-green stone called malachite. The last

substance is of particular interest, since from it copper was obtained: it is, in fact, an ore of this metal. The Egyptians were very fond of copper and used it a great deal. Our museums contain many of their mirrors, locks, keys, bolts, spoons, nails, daggers, axes, chisels, knives and other objects made of copper, or of bronze, which is composed of copper and tin. Some idea of the skill with which copper was worked can be obtained from the fact that, near the ancient town of Memphis, a copper tube 400 metres long, 4 centimetres in diameter and with walls 1 millimetre thick, was found in a temple dating back to 2500 B.C.

Similar skill was shown by the Egyptians in mathematics, the art of calculation, and also in many other fields of learning. Yet they never really succeeded in thinking about these things very clearly, and used them only for purposes of immediate practical account. If we can believe the ancient stories, the first man to understand that there was something more in the practical arts than this was one HERMES, who was later on regarded as the god THOTH (see Fig. 2). Thoth was the god of the moon, of mathematics, and indeed of all learning, and, in his earthly form of Hermes, is said to have written no less than 36,000 books! If he ever lived he must have been a remarkably fine teacher, for he is reported to have said, "I taught my son science in three days and used no apparatus, not even a retort!"

FIG. 2. THOTH

As we have seen, the Egyptians mixed up their true knowledge with much that was shallow, superstitious and inaccurate. To this latter kind of "knowledge" we may give the name of *magic*, and, as everybody knows, the Egyptians were, and still are, great magicians. Those whom Moses confounded have their successors in Egypt

even yet, who work wonders no less amazing. From its earliest days, therefore, science has been connected with magic, and, as a matter of fact, the struggle which science had to make in order to free itself from its unwelcome companion lasted over several centuries.

All the scientific knowledge, and the magical practices, that the Egyptians had gathered together were preserved very jealously by the priests. It is said that the temples had workshops and laboratories attached to them, and that only very carefully chosen disciples were allowed to learn the mysteries of the science of the time. To understand the reasons for this secrecy, we must remember that the Egyptians were sharply divided into two classes, a numerous class of common people not much better than slaves and a ruling nobility comparatively few in number. This division of the nation into rulers and ruled may have arisen through some clever family having discovered how to predict fairly accurately, from astronomical observations and calculation, the date of the next annual Nile flood. This flood was of the highest importance to the life of the Egyptians, as their food supply was dependent upon it. They lived largely upon corn, which was grown in the muddy deposits along the banks of the Nile and would have withered in the blade if the soil had not been soaked by the water of the river.

We can easily see, therefore, that reliable information as to the next flood would be of great value, and those men who possessed it might well have obtained considerable power and influence. The secret of the calculation would be handed down from generation to generation, and further knowledge and discoveries would be added as time went on. In this way, probably, there grew up a group of educated men, small in number but great in power. To keep their power they depended upon their superior knowledge, and it thus became of vital importance to them to prevent that knowledge from leaking out to the common

people. For their own sake, therefore, the learned Egyptians made as much mystery as they could about it.

The Greek Thinkers.—On the other side of the Mediterranean, in Greece, lived people of a very different character. The Greeks found one of their greatest pleasures in reflection and deep thinking, and generally despised such humble occupations as metal-working, dyeing, and so on, which they left to the slaves. It is, perhaps, fortunate that they did so, for they were thus able to devote all their energies to their great systems of thought which have done so much to make life worth living.

That desire for knowledge, which all men possess in a certain degree, was so strong in the Greeks that many of them were not content with anything less than explaining the whole of the world at once. PLATO (427–347 B.C.) and ARISTOTLE (384–322 B.C.) were philosophers of this kind, and the explanations of the universe which they gave have influenced men's thoughts ever since. However, before explaining anything, it is necessary to know as many facts as possible about it, and the Greeks as a rule had no time to collect facts and very little inclination for such a task even had they spared the time. The result was that they had to make guesses, and, while they were sometimes right, they were more often wrong.

The chief of the early Greek thinkers was THALES, who was born at Miletus about 624 B.C., and lived till 548. He was a salt-merchant, although he dabbled in other kinds of business, and as a trader he seems to have visited Egypt and other countries, including Chaldea. From Egypt he is said to have brought back to Greece the first knowledge of geometry. He believed that the world and all things in it were made of nothing but water. HERACLEITUS (about 500 B.C.), on the other hand, who was a descendant of the kings of Ephesus but renounced his royal rank for a life of meditation, believed that all things were made of fire.

A different idea was put forward by EMPEDOCLES

(490–424 B.C.). He was a native of Agrigentum, in Sicily, where he spent most of his life. In his later years, however, he was exiled, and is said to have achieved a sensational end by jumping into the crater of the volcano Etna. Empedocles was not only a philosopher; he was also a doctor and took an active part in politics. He was by no means free from vanity, and said to his disciples, "I am an immortal god unto you; look on me no more as a mortal." In Sicily he was extremely popular, and whenever he went for a walk he was soon surrounded by crowds of admirers.

In purple vestments, with a golden girdle, with the priestly laurel bound in the long hair that framed his melancholy features, and surrounded by the hosts of men and women who worshipped him, Empedocles made his progress through the Sicilian land. He was acclaimed by thousands and tens of thousands of the populace, who clung at his feet and implored him to direct them to a prosperous future, as well as to heal in the present their sickness and sores of all kinds. He claimed the sceptre of the winds, the key of the burning sunbeams and destructive falls of rain. And he could point to examples of his might. It was he who had freed the city of Selinus from its deadly pestilence by draining its soil; it was he who had bored through a rock and opened a road for the north wind to give his native city a wholesome climate. His achievements as an engineer were matched by his achievements or promises as a physician.

According to Empedocles, the universe is composed of four eternal and imperishable elements: *fire, air, earth* and *water*. Empedocles was, in fact, the first man to maintain that air and water were entirely different substances, and his idea of the "four elements" was destined to survive for about two thousand years. He was fortunate in that his suggestion was adopted and extended by the greatest of all the wise men of Greece, ARISTOTLE.

Aristotle was born at Stagira in 384 B.C. When he was eighteen, his father—who was physician to Amyntas II.,

King of Macedon—died, and Aristotle then went to Athens and studied with the celebrated philosopher PLATO for twenty years. Later on he became the tutor of Alexander the Great, and a close friendship sprang up between the two men. After a busy life of sixty-three years, Aristotle died at Chalcis in 322 B.C.

This great man, whom the Italian poet DANTE called the chief of all philosophers (*"the master of those who know"*), did not confine himself to one subject, but took all branches of learning for his province. He was, however, particularly interested in science, and tried to find out all he could about the stars, the sun and moon, and animals, plants and minerals. He soon saw that the only way in which to make any real advance was to observe keenly and to make experiments. What do we mean by "making an experiment"? Well, suppose someone said that if we stirred a cup of tea with a certain spoon the tea would become blue in colour. We might not believe him, and we could try to prove to him that he was wrong by saying that, so far, we had never observed tea to go blue when stirred with a spoon, or by looking up "tea" in the encyclopædia and finding out whether this remarkable fact was mentioned there or not.

But a much more satisfactory way would be to make an experiment, i.e. *to put the spoon in the tea and to see what happened*. There could then be no doubt on the question. Now, up to the time of Aristotle, men had usually contented themselves with *arguing* about things like this: for some reason or other they scarcely ever tried experiments. You can easily understand how hazy and wrong many ideas became. If a great man said he believed that moles always ran backwards when they were in their burrows, no one would think of looking for himself, and presently it would be generally believed that moles *did* run backwards.

Aristotle set his face firmly against this habit of his

fellow-men, and insisted that scientific knowledge should always be based upon experiment and actual observation. Unfortunately, he was so busy that he did not always practise what he preached, and his books contain a great many mistakes which he would not have made if he had followed his own advice. Still more unfortunate was the fact that he became so famous that for nearly two thousand years people trusted him absolutely and thought that everything he said must be perfectly true. If only they had done what he told them to do, that is to look for themselves and to make experiments, they would really have been honouring him more than by slavishly believing in all the details of his many books.

Fire, Air, Earth and Water.—We saw that Empedocles believed all things to be made of four simple substances, namely, *fire*, *air*, *earth* and *water*—the four "elements." This idea appealed to Aristotle, who supported it in his writings and thus firmly established it. It seems a strange idea to us, but we can nevertheless understand the kind of reason which led Aristotle to believe in it. For example, when a piece of wood is burnt, fire is produced; the wood sizzles and splutters, showing that water is formed; jets of an airy gas come off; and an earthy ash is left. The Greeks therefore supposed that the wood was composed of these four things—fire, water, air and earth—and they argued in the same sort of way about other substances. Even metals, like gold and silver, were believed to be made up of these four elements.

Some thinkers went further. They said that when air is heated it turns into fire. On the other hand, when it is cooled it turns into water and then into earth. It ought, therefore, to be possible to change any one substance into any other: thus, by proper treatment, it should be possible to turn lead into gold. This idea had a great effect upon science, for many men, during hundreds of years, spent their lives in trying to bring this change about.

The Muslims and Science.—Alexander the Great (356-323 B.C.), the pupil and friend of Aristotle, conquered practically the whole of that part of the world known in his time. One of his conquests was that of Egypt, and here he founded the city of Alexandria. When Athens, the capital of Greece, began to decline, it was in Alexandria that Greek learning found a new home. Here Egyptians and Greeks associated with one another, and each nation learnt something from its companion. The times, however, were not very favourable to the advance of knowledge, and we find that in Alexandria true science became more and more confused with magic as the centuries passed by.

In Europe, conditions were not much better as far as science was concerned. The Roman Empire had succeeded to the Greek, and although the Romans were excellent soldiers and law-makers they had no talent for science. Of course, they had a good deal of scientific knowledge of a practical kind, as is shown by the fact that they mined metals (e.g. lead in the Mendips) and constructed huge buildings; but there is no reason to suppose that they were any cleverer in this respect than the Egyptians of three thousand years before. They certainly did little or nothing to advance the cause of science.

Fortunately, in the early years of the seventh century, an event occurred which helped to set science on its feet once more and to send it off along that broad highway which reaches right down to the present day. That event was the rise of Muhammadanism, or, to give it its proper name, *Islam*.

From time immemorial Arabia has been inhabited by wandering tribes of Bedouin, who spent most of their time in warring against one another. They were all idolaters, and their chief temple, at Mecca, contained hundreds of idols, to which homage was paid in an annual pilgrimage. The prophet MUHAMMAD (569–632 A.D.), however, after many adversities and much bitter persecution, succeeded

in converting them to the worship of the One God, and thus founded the form of religion which is known as "Islam"—a word which means "submission to the will of God."

In their enthusiasm for this new religion they forgot for a time their old hatreds, and became welded into a strong and united nation. After the prophet's death in 632 A.D., they set out on a war of conquest, and very soon the banners of Islam were floating over all the countries on the south side of the Mediterranean, as well as over Palestine, Persia, Syria and Spain.

After a time the Muslim conquerors found leisure to turn their attention to learning, and very quick and eager pupils they proved themselves to be. Trains of camels were sent to Constantinople and other towns to bring back to Baghdad all the books and manuscripts that could be procured, and the Caliphs founded colleges and observatories, libraries and hospitals all over the Empire. The Arabs were a very practical people, and so the happy result was brought about that they combined the Greek wisdom with the practical arts and crafts they learned from the Egyptians.

The chief advances in science made by the Muslims were in mathematics, medicine, chemistry and astronomy, although they did good work also in improving methods of weighing and in investigating the nature of light. Some of their most celebrated scientists were AL-RAZI (died about 930), a physician; AL-KHOWARIZMI (about 825), a mathematician who invented *algebra*; JABIR (about 750–813), a chemist; and AVICENNA (died 1036), a philosopher, and a poet as well.

How Science came to Europe.—The westernmost province of the Muslim Empire was Spain. During the time that the Arabs were in possession of this country (711–1492) their universities were the best in the world, and European students used to flock to Cordova and Toledo and other towns to

learn from the Muslim professors. A relic of these far-off days is to be found in the gowns which dons and schoolmasters wear: they are copied from the flowing garments which the Arabs in Spain used to wear and which their successors wear to this day in Arabia.

When the European students had learnt what they could, they were naturally anxious to pass on their knowledge to their fellow-countrymen, and so they began translating books of all kinds from Arabic into Latin. One of these translators, an Englishman, ROBERT OF CHESTER, performed a double service: he translated not only the chief Arabic work on algebra, but also a book on chemistry. This was the first book on chemistry to appear in a European tongue—the translation of it was finished on 11 February, 1144.

During the twelfth and thirteenth centuries the work of translation went on apace, and a great interest in science showed itself in Europe. The works of Aristotle—greatly admired by the Arabs—were read and studied, and occasionally some bold spirit was found who had the courage to try experiments for himself when he thought Aristotle was wrong. One of these experimenters was the Emperor Frederick II. (1194–1250), who, to explode the fable that barnacle-geese were hatched from barnacles (a fable firmly believed in at that time), sent for some barnacles and showed that no geese could be hatched from them. He conducted many other experiments, some of which seem very amusing to us now, and frankly states that he had often found mistakes in Aristotle's books.

Unfortunately, most people in Europe did not follow the example set them by Frederick and by the Muslim scientists, but blindly accepted everything that they found in books. Hence for several centuries there was very little real progress. ROGER BACON, a Somerset man, born at Ilchester in 1216, worked very hard to make scholars understand that science can advance only by observation

and experiment, but his words had little immediate effect. Incidentally, Roger Bacon is to be remembered as the first man to state how gunpowder can be made; it is even possible that he invented it himself.

The Renaissance.—In 1453 the Turks captured Constantinople, which was at that time one of the chief centres of learning. Fleeing from the invaders, scholars scattered themselves all over Europe, bringing with them the books of the ancient Greek thinkers. Up to this time, Europeans had known the works of Aristotle and other philosophers mainly through Latin translations made from the Arabic versions, which were themselves translated from the original Greek. Very often, in the process of translation, mistakes had been made and the meaning of important parts of the books had therefore been misunderstood. Now, however, scholars had the works in their original Greek dress, and were therefore able to understand them better. Moreover, they got to know large numbers of books which had never been translated into Arabic and of which they had thus been entirely ignorant up to that time.

This great revival of learning, the *Renaissance*, or "Re-birth," gave new life to science, and progress was soon made. A year before the fall of Constantinople there was born one of the most accomplished men that the world has ever seen. He was an Italian, and his name was LEONARDO DA VINCI (1452–1519). Famed chiefly as a painter (his portrait of Mona Lisa, preserved in the museum of the Louvre in Paris, is perhaps the finest picture in the world), he was also a great engineer, a skilful mathematician and a very good anatomist. Even this list does not complete the tale of his genius, for to his other talents he added those of a sculptor, an architect and a musician! What is of most concern to us, however, is that he was one of the first men in modern Europe to try to solve some of the problems of Nature by that method of observation and

experiment which, as Aristotle had pointed out, is the only method which can give reliable results. Had he not devoted so much of his time to painting, there can be little doubt that he would have made many important scientific discoveries. As it was, he made considerable additions to knowledge, e.g. on the properties of light and on the circulation of the blood, but his chief claim to remembrance in a book of science is his firm support of the experimental method.

LEONARDO DA VINCI

In the sixteenth century the greatest name is that of GALILEO (1564–1642), another Italian. Galileo is famous chiefly for his work in astronomy. In ancient days people believed that the earth was fixed and that the sun went round it, but COPERNICUS (1473–1543), a Polish astronomer, had tried to persuade men that this belief was wrong and that, as a matter of fact, the earth revolved around the sun instead of the sun round the earth. Galileo, who in 1592 became Professor of Mathematics at Padua University, was convinced by Copernicus's arguments, and was able to find other arguments which were even better. In 1608, a Dutch spectacle-maker named JOHANNES LIPPERSHEY had invented the telescope. A year later Galileo heard some account of this wonderful new instrument, and set to work to invent one himself. He was

successful, and in January 1610 he discovered the moons of Jupiter. The sight of these moons revolving around the planet convinced people of the truth of the Copernican system more easily than any mathematical argument, and the old system had to be abandoned. It was, however, not given up without a struggle, and Galileo suffered much persecution, since it was thought that the ideas of Copernicus were contrary to the teachings of the Bible.

A second exploit which made Galileo unpopular was his proof that Aristotle was wrong on a very important matter. According to Aristotle, heavy bodies fall to the earth, when dropped, at a greater speed than do lighter ones. Thus a 2-lb. weight, thought Aristotle, will drop twice as fast as a 1-lb. weight. Galileo did not believe this, and did what no one else had thought of doing throughout the nineteen hundred years that had passed by since Aristotle's death —*he made an experiment to test it.* Taking a cannon-ball and a bullet to the top of the leaning tower of Pisa, he released them at the same moment. *They reached the ground together!* The crowd of lookers-on, who were all warm supporters of Aristotle, had to admit that their hero was wrong, but that made them only the more angry with Galileo. At last he was exiled to Rome, and there, a blind old man, he died in 1642.

Robert Boyle and Sir Isaac Newton in England.—It was mentioned on a previous page that Aristotle's idea of the "four elements," and the further belief that even these four elements could be changed one into the other, led men to think that it should be possible to convert lead into gold. This problem in its widest form became known as the *transmutation of the metals,* i.e. the changing of the "base" or inexpensive metals, such as lead, tin, iron and copper, into the "noble" metals gold and silver. For hundreds of years the chief and practically the sole aim of chemistry was to discover methods of bringing about this transmutation. It is very unlikely that anyone ever

succeeded, but there were plenty of rogues who maintained that they possessed the secret, and by means of fair words and clever tricks deceived people who trusted them. In this way chemistry got a very bad name, and if you want to see what was thought of chemists and their practices in the time of CHAUCER (1340–1400), you have only to read the story of the "Canon's Yeoman" in the *Canterbury Tales*.

Yet in spite of all this trickery there were scores of honest workers, and the discoveries they made prepared the way for a better chemistry later on. The chief thing necessary was that Aristotle's idea of the Four Elements should be thoroughly tested by experiment. If it was found to agree with experimental results, well and good; if not, then it must be abandoned and a more satisfactory idea put in its stead.

This work was accomplished by the HONOURABLE ROBERT BOYLE (1627–91). Boyle was an Irishman, the seventh son and fourteenth child of Richard, Earl of Cork. He was educated partly at Eton and partly privately, and in 1654 he went to Oxford. Here he began to study science, a study which he continued till the day of his death, 31 December, 1691.

It is to Boyle that we owe the introduction into England of the air-pump and thermometer. The latter instrument was invented by Galileo, but was improved by Boyle and again by Sir Isaac Newton (p. 18). Boyle's main service to science, however, was that he showed that Aristotle's belief—that all substances were made of fire, air, earth and water—could not be true. He thus led chemists away from the vain search for "transmutation," and they now undertook simpler problems, in which they soon met with success. Boyle's idea of an *element* is that which we still hold to-day. He said that we should regard as an *element* every substance which we cannot split up into two or more other substances. Thus gold, which Aristotle considered to be made up of fire, air, earth and water, Boyle con-

sidered to be an element, since he was not able to split it up into anything else. Two centuries and a half have gone by since the days of Boyle, but no one has yet succeeded in getting out of gold anything but gold. We therefore still regard gold as an element.

There are about ninety elements known altogether, and we believe that every substance in the world is made up of one or more of these ninety. We may, however, be mistaken in some cases—this is for the future to show. If anyone were to prove that a substance we call an element at the present time could be split up into two or more simpler substances, we should no longer regard it as an element. Such events have occurred several times during the last hundred years, but we know better now how to investigate the question and feel fairly certain that our ninety elements really *are* elements.

Somewhat younger than Boyle was Sir Isaac Newton (1642–1727), who, from a child who appeared by no means clever, developed into one of the greatest mathematicians and scientists that the world has ever seen. In 1669 he was made Professor of Mathematics at Cambridge University, and soon became famous for his investigations into the nature of light and the action of gravity. The story of his discovery of what is known as the "law of gravity" is familiar to everyone. It was told first by the celebrated French philosopher Voltaire (1694–1778), who had it from Newton's favourite niece, Catherine Barton. Sitting one day in his garden at Woolsthorpe (near Grantham), his native village, an apple fell on his head. Instead of going into the house to put butter on the bump, he asked himself, "*Why* do things fall towards the earth?" and although he was never able to answer that question, he succeeded in showing *how* they fall, and at what rate. His results enabled him to explain the movements of the planets around the sun, and thus for the first time made astronomy into an exact science.

Newton's discoveries in mathematics, a subject in which he invented several new methods of calculation, enabled scientists to solve many problems which had previously been too hard to work out; while his researches on light and colour, though they did not always lead to good results, gave great help to those who came after him.

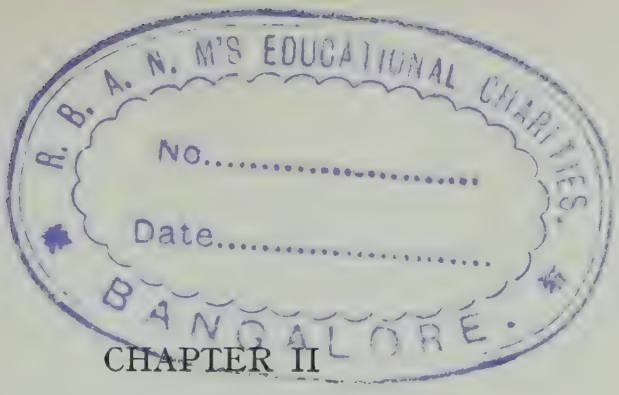
Sir Isaac Newton

Newton was so absorbed in his work that he was very absent-minded in the affairs of ordinary life. Several stories are told about him which may or may not be true, but which certainly show us how he struck his fellows. It is said that one day, when out for a ride, he came to a hill and dismounted. Holding the bridle in his hand he started to lead his horse up the hill, his mind full of some difficult calculation. When he arrived at the top of the hill he turned to mount again, but found that his horse had disappeared, leaving only the bridle in his hand. On another occasion he was giving a dinner to some friends and left them at table to go to the cellar for a bottle of wine. On his way he forgot what he went out for, put on his surplice and ended up in the college chapel.

In 1727 Newton died and was buried in Westminster Abbey. Voltaire went to his funeral, and was never afterwards tired of relating the story that in England "a professor of mathematics, merely because he was good at

his job, had been buried like a king who had done good to his subjects."

Later Development.—The death of Newton leaves us well on into the eighteenth century, in which science began to wear its modern aspect. We cannot follow its later development in detail, for the task would be too great. We shall, however, have occasion several times to describe how particular problems arose and were gradually solved by the labour of generation after generation of men of science, so that a picture of some of the more recent scientific events will slowly build itself up. We shall, for instance, see how the question of what happens when things burn led to the foundation of modern chemistry, and how research upon light enabled men to discover what elements are present in the sun and in stars a thousand times more distant. If, therefore, we leave for a moment the story of the growth of science, it is only to return, later on, to pick up the threads where we now lay them down.



CHAPTER II

WHAT CAN SCIENCE TELL US?

THERE is a proverb which says, "Seeing is believing," and there is a maxim—not seldom heard in schools—which implores us to "use common sense." With both of these fragments of wisdom science is very closely connected. We depend for our knowledge of the world upon our five senses, and upon the use which our intelligence makes of the material our senses gain for us. Now, "seeing is believing" is only a pithy way of saying that we can depend upon the direct evidence of our senses: in other words, it should be expanded into "Seeing is believing, and so are hearing, touching, tasting and smelling." "We have heard it with our ears" is quite sufficient as a rule to convince us that it—whatever it was—was actually spoken. If we smell a fragrant violet with our own nose, we confidently maintain that it does actually possess a smell.

Now, two of the principal uses of science are to show us that our senses may be mistaken and to help us to avoid these mistakes. Man's senses were originally given to him not to enable him to inquire into the secrets of Nature, but to fit him for his battle for life. Keen sight, we can be sure, is one of man's weapons with which he may defend himself from enemies, and not an instrument for observing the motion of the stars. With the growth of civilisation, man has come to use his senses for purposes very different from those for which they are properly adapted, and he has also developed a habit of thought and

reflection about what his senses tell him. It is clear that, if we are going to use our senses in order to solve the problems of the world around us, we must first be sure that they are telling us the truth.

But are they? Well, for purposes of everyday life they are usually fairly truthful, but even here they occasionally mislead us. Thus, very often, when we are sitting in a stationary train and a train parallel with it begins to move, we think that it is our train which is moving. Standing at the end of a pier and watching a steamer approach often gives us the feeling that the steamer is still and that the pier is moving to meet it. An impression of this sort may be very strong. Thus the profligate CASANOVA, in his *Memoirs*, relates the following story. When a child, he was being taken from Venice to Padua along the Brenta Canal.

> The bed was too low [he says] for me to see the land; I could see through the window only the tops of the trees along the canal. The boat was sailing with such an even movement that I could not realise the fact of our moving, so that the trees, which, one after the other, were rapidly disappearing from my sight, caused me an extreme surprise. I exclaimed to my mother, "What is this? The trees are walking!" At that very moment two friends came in, and reading astonishment on my countenance, they asked me what my thoughts were so busy about. "How is it," I answered, "that the trees are walking?" They all laughed, but my mother, heaving a great sigh, told me in a tone of deep pity, "The boat is moving, the trees are not. Now dress yourself." I understood at once the reason of the phenomenon. "Then it may be," I cried, "that the sun does not move, and that we, on the contrary, are revolving from west to east."

Casanova was, of course, right. The sun does *appear* to move across the sky from east to west, but here our senses deceive us: the movement is really one of the earth, from west to east. Our eye, again, may fail us through being too slow. When, at a fair, we watch the man with the three thimbles and the pea, we feel perfectly certain

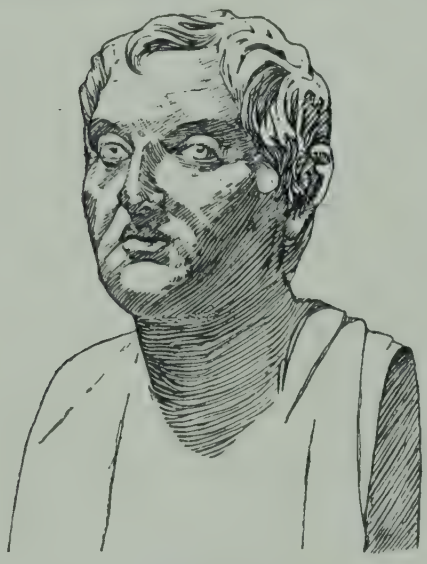
that we know which thimble the pea is under. Yet when the thimble is lifted, lo! the pea has vanished. Let us take still another example. When we put a straight stick into a pool of water, the stick appears to be bent, but when we take it out it is as straight as ever.

It is not only the eye which thus deceives us. If we cross two fingers and put a penny between them, we could swear that we were touching *two* pennies. When we shout, and our words are borne to us again by the echo, it seems exactly as though someone were answering us from a distance. If we put one hand into hot water and the other into snow, and then plunge them both into lukewarm water, the hand which has been in the snow will tell us, "This is hot," while the other will say, "It is cold."

Our senses, in fact, while exceedingly useful and reliable for ordinary purposes, are, even here, not always absolutely trustworthy. They tell us only what things *seem to be*, whereas in science we hope to find out what they *are*. One of the first duties of science, therefore, is to show us how to check the information our senses give us, and how to sort out what is true from what is false. Seeing is not always believing, and if this is so, we must find out when our eyes are to be trusted and when they are not.

"Use your common sense, boy!" must have been said by many an angry father and impatient schoolmaster, but they might have found it difficult to say exactly what they meant by common sense. Unfortunately, the person to whom they address the command is rarely in a position to ask them. What they probably mean is, "Apply to the problem under consideration the experience you have gained from previous problems of the same or a similar kind." This is a very sound maxim, as useful in science as in everyday life, and it implies that one's stock of common sense increases with experience, which is generally true. But science comes in with the very pertinent question: "This experience of yours is all very well for the problems

of daily life, but does it really tell you the truth about things?" Alas! the answer is *no*! For example, suppose you were to take a litre of water and a litre of alcohol and mix them. What would the volume of the mixture be? Common sense answers, "Two litres, of course," but it would be wrong. The mixture would occupy much less than two litres. Consider a red cricket-ball. Is it red when no one is looking at it? Common sense says, "Of course it is. What a silly question!" But the sensation of redness is caused in the eye by the rays of light coming from the ball. Hence, if there is no eye there can be no redness—so common sense is wrong again. Remember Aristotle and the rate at which things fall. Aristotle said that it was only common sense to believe that a heavier object falls more quickly than a lighter one; but he was wrong, as Galileo showed.



ARISTOTLE

Common sense, in short, which—like the senses themselves—serves well enough for many purposes, often fails us if we follow it too blindly. To use it in its crude form in order to unlock the secrets of Nature is rather like using a sledge-hammer and chisel to investigate the works of a watch. The senses, and that rough form of intelligence which we call common sense, have then to be sharpened and polished and refined before we can confidently trust in all that they tell us, and this is one of the tasks of science.

It is practically impossible to sharpen the senses to any great extent. It is true that they can be trained and thus made more efficient, but they are actually very little, if any, more sensitive after the training than they were

before. If we cannot see the thing that is under our very nose, it is not because our sight is bad, but because we are not using it. Similarly, if we are reading a thrilling novel of hidden treasure, pirates and secret passages, the reason that we do not hear the clock strike is that our attention is fixed on other things. In science, therefore, we have first to train the senses so that they may become as useful as possible; but this in itself is not enough. There are extremely tiny plants, called germs or bacteria, which are so minute that even the keenest sight could not perceive them. It is of no use training the eye in the hope that after a time it will be able to see bacteria. We must *help* the eye by providing it with a microscope. In the same way, the faint sounds which are produced in the sound-box of a gramophone are magnified by the horn so that the ear may readily catch them. Scientific instruments, then, are in the main intended to aid the senses and in some cases to correct them.

Common sense, again, to be useful in science, has to be very carefully trained, otherwise it will jump to conclusions too soon. The results it obtains have to be checked at every turn and any doubtful one must be reinvestigated time after time until the mystery is cleared up. When it is properly trained in this way it becomes the most valuable aid to knowledge, and indeed the great biologist HUXLEY once said that science is only "organised common sense."

Why we believe what Science tells us.—Since, in science, we take nothing on trust, and are perfectly ready to disregard even the plainest evidence of our senses if they can be shown to be wrong, we firmly believe in the truth of our results. For example, we firmly believe that the earth is a sphere and that it revolves around the sun, although our senses may try to make us believe that it is flat and that the sun moves round it. But—and here comes a very important point—we should be perfectly ready to alter our belief if some fresh evidence came along to show

that our old idea was incorrect. When, in fact, we say in science that we believe a thing to be true, we do not mean the same as when we say we believe in the various articles of the Apostles' Creed. We say a thing is "true" in science when it satisfactorily explains a lot of facts by enabling us to see a reason for them, and when nothing is known with which it does not agree. For example, we believe it to be "true" that all things are made of electricity, but what we actually mean is that, by *supposing* that all things are made of electricity (i) we can understand a lot of very puzzling facts, and (ii) we do not know anything which will not fit in with that idea. Science is, however, always advancing, and we may have to abandon this belief in favour of a better one. This is an event which has often happened in the history of science, and although we know a good deal more about the world than our forefathers did, there is no reason to suppose we know anything but a tiny fraction of all there is to be known.

What Science cannot tell us.—Since science is based on nothing more than reasoning from material supplied by our senses, and since we know that our senses are not always to be trusted, even when trained and assisted, it follows that science can tell us nothing whatever about things that cannot be seen or heard or tasted or smelt or touched. Hence all that part of our life which has to do with religion and like matters can be affected by science only in so far as the latter teaches us to reason carefully and honestly and to inquire into the why and wherefore of everything. This is too deep a question to be considered here, but it must be said that those people (less numerous now than in the days of Queen Victoria) who have tried to show that by science alone can man reach Truth, have failed to understand what science can tell us and what it cannot.

What Science enables us to do.—As we saw in Chapter I., men study science because they have a thirst for knowing, and also because the knowledge they gain enables them

to make the world a better place. What science tells us, then, we can turn to practical advantage in two ways: First of all, we can use the habit of careful thought and methodical investigation, which is characteristic of science, in those other branches of our life which are of no less importance. To take an example of a general kind which is fraught very often with far-reaching consequences: we learn not to take any opinions merely on the authority of others. We realise that we must find out for ourselves, and not come to a conclusion till we have all the facts before us. If this rule, which is the life-blood of science, were observed in other worldly affairs, what a difference it would make!

Secondly, science benefits us in a material way. The telephone, the telegraph, machines and engines of all kinds, our clothes, our medicines, our very food supply itself are all dependent upon the work of scientists. To see what science has done to improve the lot of the human race, we have only to look around us. The compass which directs a ship, the engines which propel it, the wireless which brings it news from land and often saves it when in distress are a few of the inventions which the scientist has given to the world. When our civilisation is so bound up with scientific achievement, the difficulty is not to find where science has been of value, but where it has not. Here perhaps you will say—in warfare. It is certainly true that scientific discoveries have placed in the hands of man weapons far more terrible than he ever possessed before, but the responsibility for their use does not lie with the scientist. A man may use a telephone to lure a victim to his death, but the responsibility does not lie with Dr. Bell, who invented the telephone. Science gives us these discoveries: it is we ourselves who are responsible for using them properly. It would scarcely be fair to call the man who invented bolsters a murderer simply because the princes in the Tower were smothered with one.

Why Everybody should know Something of Science.—Very often young people ask, "Why should I study science? I am not going on with it after I leave school and I do not see of what use it will be to me." If you have carefully read the preceding paragraphs, perhaps you will already know what the answer to that question is. It is not because you will learn such facts as "zinc is an electro-positive element of atomic weight 65" that we believe you should all learn science. Facts of that kind may possibly prove useful to you afterwards, but more probably you will soon forget all about them. We believe that you should get some acquaintance with science chiefly because science, better than any other branch of knowledge, will teach you the spirit of honest inquiry, the impartial weighing of facts, and the tremendous value of truth in human life. We believe also that, by a study of science, your eyes will be opened to new beauties in the world around you, that the scientific spirit will give you sympathy and understanding for your fellow-men, and that your whole life will be broadened and deepened and given a wider and a nobler aim.

CHAPTER III

AIR

The Four Elements again.—Aristotle, as we know, thought that the whole of the world and all the substances in it were made up of four elements, namely fire, air, earth and water. Even to-day we sometimes use the word "elements" in this sense, as when we talk about the "fury of the elements" during a storm. Fire, air, earth and water do in fact correspond to a classification of substances which we can all understand and which we ourselves have all made; air is typical of gases, earth of solids and water of liquids, while fire represents one of the most striking occurrences of everyday life—the process of burning. In beginning the study of science we cannot do better than to take each of Aristotle's four "elements" in turn and find out all we can about them. Let us begin with air.

Air has Weight.—The air which surrounds us has a fascination all its own, for it is invisible. It may seem an impossible task to find out very much about this elusive substance, and, as a matter of fact, it was not until a couple of centuries or so ago that men began to achieve success. Colourless, tasteless, odourless, difficult to touch, how can air ever be made to submit itself to our investigation?

FIG. 3. GLOBE FOR WEIGHING AIR

We can begin by taking a glass globe, fitted with a tap, as shown in Fig. 3. Let us fix this on to an air-pump and pump all the air out. We shall now have a globe containing nothing at all: it has, in fact, been *evacuated* or "made empty," and the

space inside is a *vacuum*. Just as water can be pumped out of a ship by means of a water-pump, so can air be pumped out of a closed vessel by an air-pump. Of course, since the earth is surrounded by air, care must be taken not to let any leak into the vessel which is being evacuated—it would not be much good trying to pump all the water out of a bucket which was kept under the surface of the sea!

When we have got the globe empty, let us weigh it. Then we will open the tap and let the globe fill with air, after which we will weigh it again. If air has any weight, the second weight should be greater than the first, and the difference between the two will give us the weight of the air in the globe. In an experiment of this kind, the following figures were obtained:

Weight of globe filled with air ..	110·11 grams
Weight of globe empty	108·70 grams
Difference, i.e. weight of air ..	1·41 grams

The globe would hold exactly 1000 c.c. or 1 litre.

Hence 1 litre of air weighs 1·41 grams. Now the atmosphere as a whole has a volume of millions of millions of litres, and therefore its total weight is enormous. Exactly what it is we do not know, but it must be trillions of tons. This may seem a very strange fact to you, yet you see it can be proved by the simple experiment just described, followed by an estimation of the total volume of all the air surrounding the earth.

Air exerts a Pressure.—If air has so much weight, it must be pressing very heavily on all bodies on the surface of the earth. Measurements have been made to find out how great this pressure is, and it has been shown to be about 15 lb. on every square inch. We can measure it ourselves very easily by means of the *barometer*. This consists of a glass tube, about 33 inches long, closed at

one end. It is filled with mercury and then inverted in a trough of mercury (Fig. 4). When the tube has been arranged in this way, it is found that the mercury does not all fall out of the tube, but that a column of it about 30 inches high remains. Between the top of the mercury and the closed end of the tube there is a space. Here then we have two problems: (*a*) What is in the space at the top of the tube? and (*b*) Why does the mercury not fall out? Let us deal with (*b*) first. The atmosphere is pressing very hard on the surface of the mercury in the trough, and hence the mercury in the tube cannot get out. It fell down a little way in the tube because at first the weight of the column was greater than the pressure which the air was exerting on the mercury in the trough. Hence mercury came out; but when the weight of the mercury left in the tube exactly balanced the pressure of the air on the mercury in the trough, no further change took place. As to the space at the top of the tube, there can be nothing whatever in it, for the whole tube was filled with mercury to start with, and no air has been allowed to enter. Hence this space is a vacuum. We call it the *Torricellian vacuum*, because Torricelli was the first to carry out the experiment just described.

FIG. 4. BAROMETER

Suppose we had a tube twice as wide as the first, filled it with mercury and inverted it in a trough of mercury. How high would the mercury column in the tube stand in this case? What an opportunity for discussion this would have afforded the ancient scientists! They would probably have argued about it for years. We, however, adopt a different plan—we simply take the tube and the mercury and try the experiment for ourselves. What do we find? We find—perhaps to our amazement—that the mercury column is of exactly the same height in the wide tube as

in the narrow one! That is, the pressure of the air is supporting much more mercury in the one case than in the other. The apparent strangeness of this fact disappears when we remember that, although the pressure has to support more mercury in the wide tube, it has a wider space over which to act. Horatio held the bridge against an army because the army could exert its pressure over only a very small area, merely the width of the end of the bridge. Similarly, the space over which the pressure of the air can act on the mercury in the tube is the cross-section of the tube. The wider the tube the greater the opportunity for the pressure and thus the more mercury it can support.

In short, whatever the width of the tube, we find that the height of the column of mercury which the air can support is always the same. This height is called the *height of the barometer* ("barometer" comes from the Greek and means "measurer of heaviness." It is applied to the instrument described because it means the pressure of the atmosphere).

If we took a barometer and observed it over a period of several days, we should notice that the height of the mercury column varied slightly from time to time. At sea-level it is usually about 76 cms. or 30 inches, but in fine weather it may be greater and in wet weather less. This means that the pressure of the air changes, for otherwise there would be no reason for the height of the mercury to change. The column becomes shorter on the approach of rain (or the barometer "falls") because the air then contains a great deal of water-vapour, which is a lighter gas than air. A mixture of air and water-vapour is thus lighter than the same volume of ordinary air and hence cannot exert so great a pressure. The barometer therefore falls.

Naturally, too, the height of the barometer becomes less when we ascend a mountain with it, for there is less air above us than there was when we were at sea-level, and

hence the atmospheric pressure is less. The higher we go, the less the pressure becomes, and therefore the lower the mercury falls. On the other hand, if we go down a mine, we shall find that the height of the barometer increases, for there is now more air above us and therefore the pressure is greater.

Liquid Air.—When we boil water it turns into a colourless gas which we cannot see and which we call steam. If the steam is allowed to cool, the steam turns back to liquid water again. Look, for example, at the spout of a kettle containing boiling water (Fig. 5). You will notice that, just at the spout, you can see nothing, although steam is certainly there—as you learn if you accidentally put your hand in it. A little farther away, however, there is a white cloud, which consists of tiny drops of water formed when the steam is cooled by the air around. This change of steam into water is called *condensation*, while the reverse change of water into steam is known as *evaporation*. In exactly the same way, if we take mercury and boil it, it will evaporate and form an invisible gas, which is called mercury vapour. On cooling this vapour it condenses and forms liquid mercury again.

FIG. 5. STEAM ISSUING FROM KETTLE

Since by cooling steam and mercury vapour we can get liquids, why should it not be possible to turn air into a liquid? Well, it is possible. If air is cooled to a temperature of -200° C., i.e. nearly 200° Centigrade below the freezing-point of water, it condenses to a colourless liquid which is known as *liquid air*. To get this low temperature, a very ingenious device is used. The air is compressed strongly by means of a pump worked by a gas-engine and is then

allowed to escape through a very tiny hole. When it is released from the pressure in this way, it suddenly expands to its original volume, and in doing so it gets colder. This cold air is then allowed to circulate around the pipes through which passes the compressed air, and the latter itself is thus cooled. The next lot of air which escapes through the tiny hole is therefore colder than the first, and after expansion becomes colder still. In its turn it cools the compressed air, and so the process goes on until the air which comes through the hole is so cold that it condenses to a liquid, which drips down into a vessel put to receive it. A liquid air plant is shown in Fig. 6, and a diagram to explain how it works in Fig. 7.

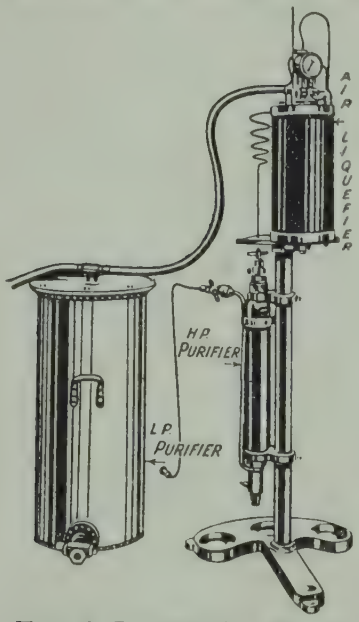


FIG. 6. LIQUID AIR PLANT

As liquid air is so much below the temperature of an ordinary room, it has to be preserved in special apparatus, otherwise it would boil away far too rapidly. The cups and glasses used for the purpose have two walls, the space between them being a vacuum. Heat cannot pass easily through a vacuum, and hence the air remains cold. The walls of the vessels are, moreover, silvered; the silver acts as a reflector and reflects back any heat which may strike it, just as a mirror reflects light. This kind of apparatus was invented by SIR JAMES DEWAR (1842–1922).

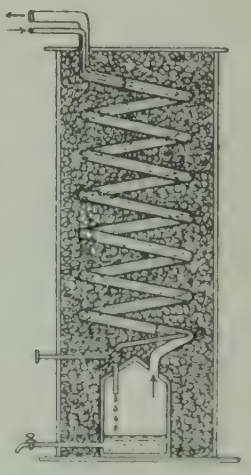


FIG. 7. HOW A LIQUID AIR PLANT WORKS

When liquid air is allowed to boil it changes back again into ordinary air, i.e. it evaporates. The temperature at which it boils is $-190°$ C., so that melting ice, which has a temperature of 0° C., is very hot in comparison. Hence, if liquid air is poured into a kettle, and the kettle then placed on a block of ice, the air inside boils vigorously. The air which comes out of the spout is still so cold, however, that all the water vapour in the air in the neighbourhood is condensed to water, and hence a cloud is produced just as if the kettle contained boiling water. (See Fig. 8.)

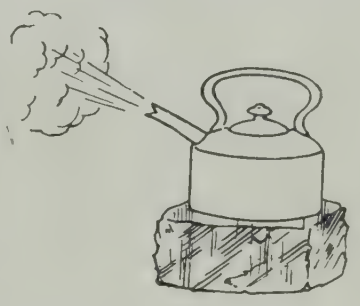


FIG. 8. LIQUID AIR BOILING IN A KETTLE ON ICE

When various objects are placed in liquid air, the very low temperature often makes them behave in unexpected ways. Thus, when mercury is used, it is at once frozen to a hard solid; while, when rubber is put in liquid air for a few minutes, it becomes so hard and brittle that it can be shattered into fragments with a hammer! A piece of steak, after being immersed in liquid air, is converted into a solid block which can be taken out and powdered in a mortar; while grapes become as hard as marbles and crack when dropped upon the floor.

The Rusting of Metals.—So far we have found that air is a material substance, for it has weight and it can be liquefied. We shall be able to discover more about it if we inquire into an event which you must all have noticed, namely, the rusting of a piece of iron when it is left out-of-doors. Rusting, as is well known, takes place much more quickly in wet weather than in dry, which would lead us to expect that water has something to do with the process. Perhaps water by itself is sufficient to cause iron to rust: how can we tell? Clearly the easiest way would be to leave iron in contact with water and *nothing else*. If the iron

rusted we should know that water alone was quite sufficient. The other substance which might have something to do with rusting is air, for, since iron rusts when it is exposed to moist air, the cause of the change must lie (*a*) in the air alone, or (*b*) in the water alone, or (*c*) in both together.

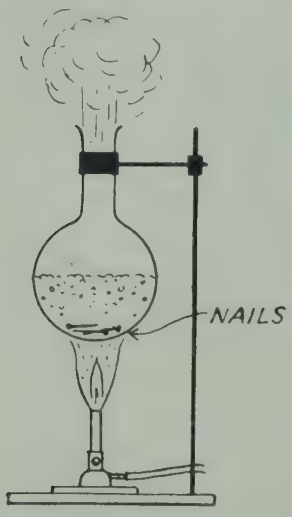


FIG. 9. DRIVING AIR OUT OF THE WATER AND FLASK

Let us try the water first. If you gently warm some water in a clean flask, you will notice that bubbles of a gas soon begin to come off. If these bubbles are collected and examined, it is found that the gas is *air* which has been dissolved in the water and is being driven off by the heat. Hence, for purposes of our investigation, it would not be fair to take ordinary tap-water, for in that case we should really be using air as well.

We can get over the difficulty in this way: we take a flask, and into it put a few bright iron nails and 100 c.c. or so of water. We then boil the water vigorously for ten minutes or a quarter of an hour. The air dissolved in the water is thus removed, and, in addition, the steam drives out all the air in the flask (see Fig. 9).

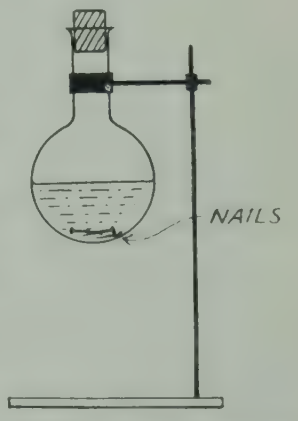


FIG. 10. CORKING THE FLASK CONTAINING ONLY WATER AND NAILS

We then take a rubber stopper and firmly cork the neck of the flask, at the same moment removing the flame so as to avoid bursting the flask (Fig. 10). When the latter is cold it will contain nothing but iron and water, the space above the liquid water being filled merely with water vapour. We can now leave the flask for a few days and

watch for any sign of rusting. It will be found that no rust whatever is formed: there is in the chemical laboratory at Clifton College a flask prepared in this way which has been left for over ten years, and the iron is still as bright as on the day it was put in! We see, therefore, that *water alone is not sufficient to cause iron to rust.*

Now let us make another experiment to find whether *air* alone will make iron rust. Here again we shall have to be careful, for ordinary air is damp. You can easily prove this by putting a little ether in a narrow beaker and blowing a current of air through. The ether evaporates, and in so doing becomes very cold. It also cools the air immediately surrounding the beaker, and the cold air can no longer hold all its moisture, which is deposited as dew on the outside of the beaker.

If, therefore, we want to find whether air alone is sufficient to make iron rust, we must first of all *dry* our air. We can do this by using a substance which has a great affection or "avidity" for water and will therefore remove it from damp air. Such a substance is *calcium chloride*, a white solid which is obtained as a waste product in the manufacture of washing-soda. A glass jar with a waist (Fig. 11) is taken, and the lower part is filled with calcium chloride. When the lid is put on the jar, the air inside soon has all its water vapour removed by the calcium chloride, and thus becomes quite dry. This piece of apparatus is called a *desiccator* (from the Latin *siccus*, dry), and you should note carefully how to spell the name, for it is a word very commonly misspelt even by those who are old enough to know better! The upper

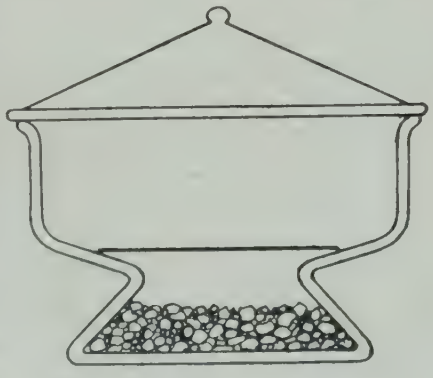


FIG. 11. A DESICCATOR

portion of the jar is divided from the lower by a piece of zinc gauze, which serves as a shelf upon which to rest anything we wish to place in the desiccator.

On this shelf let us put a piece of filter-paper and then two or three bright iron nails. We will then close the desiccator and leave it. We shall find that, even after several weeks, no rusting has occurred; hence our second conclusion is that *air alone is not sufficient to make iron rust.* Now, if air alone, or water alone, or air and water together, are the three possible causes of the rusting of iron, and the first two are rejected, we conclude that the rusting must be due to *air and water together.* To test this, let us take the stopper out of the sealed flask containing nothing but water and iron and see what happens. In a few hours the iron is covered with rust! Hence our conclusion is justified.

To prevent iron structures from rusting, then, we could dry the air or remove it. Since these measures are impossible to carry out in the open, a different method has to be adopted, namely, the bridge or other object is covered with a coat of paint, which prevents the damp air from reaching the iron.

Change in Weight on Rusting.—When we take iron and let it rust, we start with a bright metal and finish with a red powder. What has happened? The ancients believed that the "life" of the metal, a kind of "spirit," had departed, and that the rust was just the "dead" and earthy residue. Now, whether or not something has left the metal we can easily find simply by weighing the metal at the beginning and the rust at the end. If the rust weighs less than the metal, then we shall know that, during rusting, the metal *loses* something. On the other hand, if the rust weighs more than the metal, then the metal must have *taken up* something.

Suppose we take a basin and weigh it, and then put into it some iron filings and weigh again. The difference

between these two weights will give us the weight of the iron. Next we will add a little water (why?) and leave the basin for a few days. During this time the iron will rust. We must now put the basin in an oven to drive off all the moisture that is left, and we shall then have just the dry rust in the basin. Then we weigh the whole once more, thus getting the weight of the basin *plus* rust. By subtracting the weight of the basin we get the weight of the rust. In an experiment of this kind the following figures were obtained:

(*a*)	Weight of basin and iron ..	36·2 grams
	Weight of basin alone ..	34·1 grams
	∴ Weight of iron ..	2·1 grams
(*b*)	Weight of basin and rust ..	38·1 grams
	Weight of basin alone ..	34·1 grams
	∴ Weight of rust ..	4·0 grams

In other words, when iron rusts it *takes up* something, for the rust weighs more—much more—than the iron. This is a very important result, and it shows us that the old idea was wrong. Instead of *losing* anything, the iron *gains* something, and our next task must be to find what this something is.

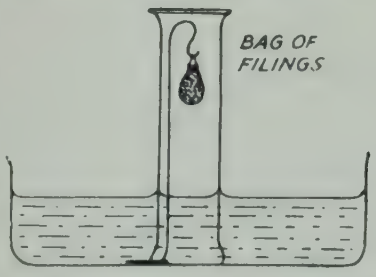


FIG. 12. IRON RUSTING IN ENCLOSED VOLUME OF DAMP AIR

What does Iron combine with when it Rusts?—An experiment which will help us to answer this question you may easily carry out for yourself. Take a glass jar and invert it in a trough of water (Fig. 12). You will now have a definite volume of air confined in the jar, and this air will be quite cut off from the surrounding atmosphere. Put some iron filings

into a muslin bag and, after damping well, suspend the bag in the jar by means of a piece of wire (Fig. 12). Then leave the apparatus for a few days, so as to allow the iron to rust.

You will find that, for a day or two, the level of the water in the jar will gradually rise, showing that air is being used up. After a while, however, no further rise occurs. This takes place when the water has risen to the extent of about one-fifth of the height of the original volume of air. If you now take out the bag and open it you will find that, although there is plenty of rust, there is still some unrusted iron left.

What do these observations tell us about the process of rusting? In the first place, they tell us that the "something" with which iron combines when it rusts is *part of the air*. Why is it *only* "part"? Clearly (i) because, although there was some iron left in the bag, it did not rust, and (ii) because, when this happened, there was still four-fifths of the original air left.

Hence we have made the important discoveries that when iron rusts it takes up something from the air, and that this part of the air forms one-fifth of the whole. We can thus be quite certain that the air consists of at least two different gases, one of them, which we can call "active air," since it takes part in rusting, forming one-fifth, and the other, which we can call "inactive air," forming four-fifths.

Properties of Inactive Air.—When "inactive air" was first isolated 150 years ago, scientists put mice and other small animals into it to see how it affected them. It was found that they soon died; so that besides being inactive as regards rusting, it is also useless for supporting life. The great French chemist LAVOISIER (1743–94), who was guillotined during the French Revolution, therefore called it *azote*, which means "without life." It has since been discovered that azote is a constituent of saltpetre, or

nitre, and for this reason we usually call it *nitrogen*, or "the nitre-producer."

If we put a lighted taper into a jar of inactive air (or nitrogen as we shall call it in future), we shall make another interesting discovery, namely, that the flame is at once extinguished. We have found, therefore, four things about nitrogen: (i) it forms four-fifths of the air; (ii) it does not cause iron to rust; (iii) it will not support life; (iv) it will not allow things to burn in it. These qualities we call "properties" of nitrogen, using the word in the same sense as in the phrase "the property of the Lord is always to have mercy."

Now, if air will cause iron to rust and will support life and burning, and nitrogen will not, it is obvious that these properties of air must be due to the other constituent, namely, the "active air," which forms one-fifth of the whole. We must therefore try to find out more about active air and attempt to get it by itself, so that we can examine its properties.

The Burning of Metals.—If we leave a piece of bright magnesium ribbon exposed to damp air, it slowly rusts, but in this case the rust is a *white* powder. Magnesium, unlike iron, is a metal which, when heated, will take fire and burn brilliantly in the air, and when it burns it leaves a white ash. Now, if we take magnesium rust and dry it and then compare it with the ash left after burning the metal, we shall find that they appear to be very similar. Chemists have investigated this question and they have found that, as a matter of fact, the two substances are not merely very similar: they are *identical*. Here, then, we have another interesting fact, namely, that rusting a metal is practically the same as burning it slowly. In other words, when a metal is burnt in air it combines with the "active" air and leaves the nitrogen.

This gives us a clue to a possible method of getting active air free from nitrogen. Suppose, in some way, we

could persuade the magnesium ash to give up its active air again. We could then collect the latter and find out its properties. Well, magnesium ash is rather stubborn, and it refuses to part with its active air. Fortunately, however, another metal is more easy-going and will do what we want it to do. That metal is quicksilver, or *mercury*.

Mercury and Active Air.—If we heat mercury in the air it will not burn, but if we keep it in air for some days at a temperature just below its boiling-point (357° C.), it will gradually rust, forming a red powder. If this powder is

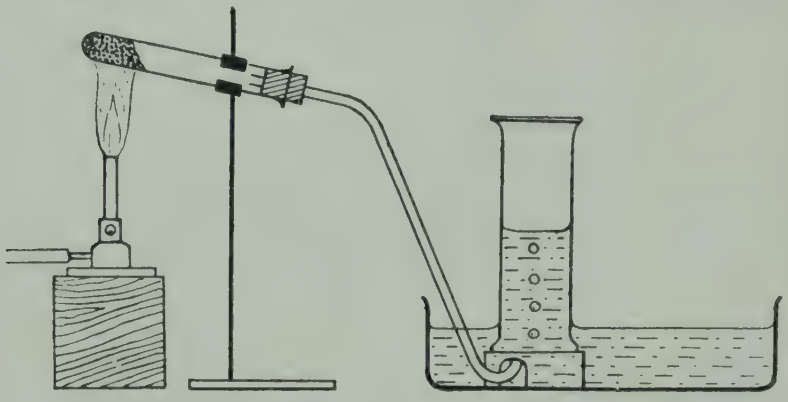


FIG. 13. PREPARATION OF ACTIVE AIR

then heated to a higher temperature, it splits up again into the two things of which it is made, viz. mercury and active air. We will therefore take a few grams of it and put it into a test-tube fitted with a cork carrying a delivery tube, as shown in Fig. 13. The delivery tube leads to a trough of water, and over it we place a gas-jar filled with water. When we heat the test-tube we shall see that drops of mercury are formed and that bubbles of a gas come off from the delivery tube and, rising into the gas-jar, displace the water there and finally fill the jar.

By this method, therefore, we succeed in isolating active air. Now, what properties should we expect it to have? First of all, if we place sufficient moist iron in it, it ought

all to be used up. This is found to be so. Secondly, it ought to support life very well, and here again our conclusion is found to be correct: active air is, in fact, often used (under another name) to keep sick people alive as long as possible. Thirdly, it should support combustion (i.e. allow things to burn in it) very readily. You can try this for yourself by plunging a red-hot splint of wood into the gas: the splint will at once burst into flame. Magnesium burns in it with dazzling brilliancy, and even iron, which will not burn in ordinary air, can easily be burnt in active air (see Fig. 14).

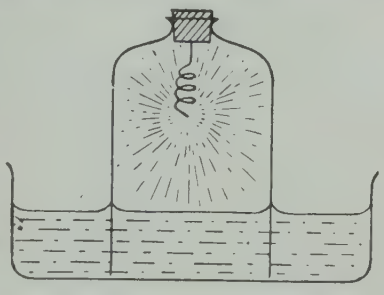


FIG. 14. IRON BURNING IN ACTIVE AIR

Oxygen.—If you taste vinegar or the juice of a lemon, you say that the flavour is *acid*. A very characteristic property of acid liquids is that when they are poured on to washing-soda or marble a "fizzing" or effervescence is produced. The whole mass seethes and appears to boils owing to the vast number of bubbles of a gas which come, off. The action of vinegar upon soda has been known for a very long time, for it is mentioned in the Bible by the Prophet JEREMIAH.

Another property which acid substances possess is that they will turn blue litmus red. Litmus is a blue colouring-matter obtained from certain plants which grow in sub-tropical regions. When it has been purified, it is dissolved in water and the solution so made is used as a *test* for acids. Any substance which will turn blue litmus red is called an acid. Those acids which are found in lemon-juice and in vinegar are very weak acids. Much stronger ones are *sulphuric acid*, which is made from sulphur; *nitric acid*, made from nitre, or saltpetre; and *hydrochloric acid*, which can be obtained by pouring sulphuric acid upon common salt.

All three of these substances, and in fact acids in general, have the following properties:

(i) They will turn blue litmus red.

(ii) They will cause an effervescence if they are mixed with water and then poured on to marble or soda.

(iii) They have an "acid" taste.

FIG. 15. DEFLAGRATING-SPOON

Now, it is a remarkable fact that nearly all acids, when analysed, are found to contain "active air." Indeed, Lavoisier, who was mentioned on p. 40, thought that *every* acid contained active air, and hence he called active air *oxygen*, a name which comes from the Greek and means "acid-producer." He was not quite right, for hydrochloric acid and prussic acid, as well as a few less common acids, do not contain oxygen, but the name has stuck to the gas and is not unsuitable for it.

Starting with oxygen, we can easily make one or two acids. Suppose we leave a piece of phosphorus in a jar of oxygen. Phosphorus is a yellow waxy element made from bones, and takes fire so readily in the air that it has to be kept under water. If we put a small piece of it in a deflagrating-spoon (Fig. 15), light it, and then plunge the spoon into a jar of oxygen, we shall be dazzled at the brightness of the flame. After a time, all the phosphorus will have burnt and we shall notice that the jar is filled with a white smoke, part of which settles on the side of the jar as a light powder. Just as mercury rust is composed of *mercury* and oxygen, so is this powder composed of *phosphorus* and oxygen: chemists therefore call it *phosphorus oxide*. In the same way, they call mercury rust *mercury oxide*, iron rust *iron oxide*, and magnesium rust *magnesium oxide*.

When phosphorus oxide is added to water, it makes a hissing noise, like that produced when a red-hot poker is quenched. If we tested the liquid so formed with blue litmus, we should find it to be strongly *acid*. In fact, when phosphorus oxide is dissolved in water, *phosphoric acid* is formed. Similarly, when we have sulphur in oxygen we get sulphur oxide, which is a gas, and when this gas is dissolved in water *sulphurous acid*—a first cousin to sulphuric acid—is obtained. Hence we see that the name "oxygen" for active air is a very reasonable one.

A Recapitulation.—Let us stop for a moment and take stock of what we have already discovered about air. We have seen that air is composed of two gases, namely nitrogen and oxygen. The nitrogen forms about four-fifths, and is inactive: it will not support life or combustion, neither does it make metals rust. The oxygen forms one-fifth, and is a very active gas. It causes metals to rust, allows things to burn in it very brightly, and will support life. Rusting and combustion we have found to be similar processes; in each case the substance concerned combines with the oxygen of the air, forming an *oxide*. Oxygen, again, is contained in most acids and is therefore properly named, for oxygen means "acid-producer."

Commercial Method of obtaining Oxygen.—Besides being used in cases of severe illness—especially of the lungs—oxygen is employed for many other purposes, such as the production of very high temperatures. If, for example, acetylene (the gas made by acting upon calcium carbide with water) is mixed with oxygen, the mixture when lit burns with a tremendously hot flame. This *oxy-acetylene* flame is used for cutting steel and for welding rails, etc. Oxygen, therefore, is an important article of commerce and, as such, is prepared on a very large scale. The cheapest source of oxygen is obviously the air, since no Government has yet thought of charging us for that, and there are no royalties to pay on it! Oxygen is therefore obtained from the atmosphere.

The first stage consists in liquefying the air, as described on p. 34. The liquid air consists of a mixture of liquid oxygen and liquid nitrogen, and these can easily be separated from one another since they boil at different temperatures. You will be able to understand the process if you consider another example of it. Suppose we had a mixture of ether, a liquid used to send people to "sleep" during an operation, and aniline, a liquid made from coal-tar and the source of many of the dyes with which—following the example of the ancient Britons—we make ourselves gay. Now ether boils at 35° C.—just below blood temperature—while aniline boils at a much higher temperature, namely 182° C. What will happen if we heat the mixture? Well, when the temperature rises to 35° C., the ether will all boil away and the aniline will be left. We could therefore separate the two liquids in this way.

Liquid oxygen boils at about −180° C. and liquid nitrogen 10° lower, viz. −190° C. Hence, if we allow heat to get at liquid air, as soon as the temperature rises to −190° C. the nitrogen will boil away. The oxygen will not boil at this temperature, and is therefore left. After being isolated in this way, it is allowed to boil, and the gaseous oxygen is then compressed into strong steel cylinders, where it is stored for use. If you want a supply of oxygen, all you have to do is to buy one of these cylinders and turn on the tap, when the oxygen will come out; you can adjust the rate of flow by a screw-valve on the top.

Respiration.—A few pages ago it was mentioned that chemists found that animals could not live in nitrogen, but that they lived quite happily in oxygen. When we breathe, therefore, we are clearly taking in air in order to use the oxygen in it. If this is so, then the air which we breathe *out* ought to be different in some way from that which we breathe *in*. Test this for yourself by first *sucking* air through a bottle of lime-water and then *blowing* air through it. Use the arrangement shown in Fig. 16. You

will notice that in the first case the lime-water remains clear, while in the second it turns milky. Hence air which is breathed out must contain something which has the power of turning lime-water milky. What is this substance? To answer this question, take a piece of charcoal, or *carbon*, and burn it in a jar of oxygen. Although nothing visible is found, yet a change must have taken place, for after the experiment you will find that the gas in the jar is no

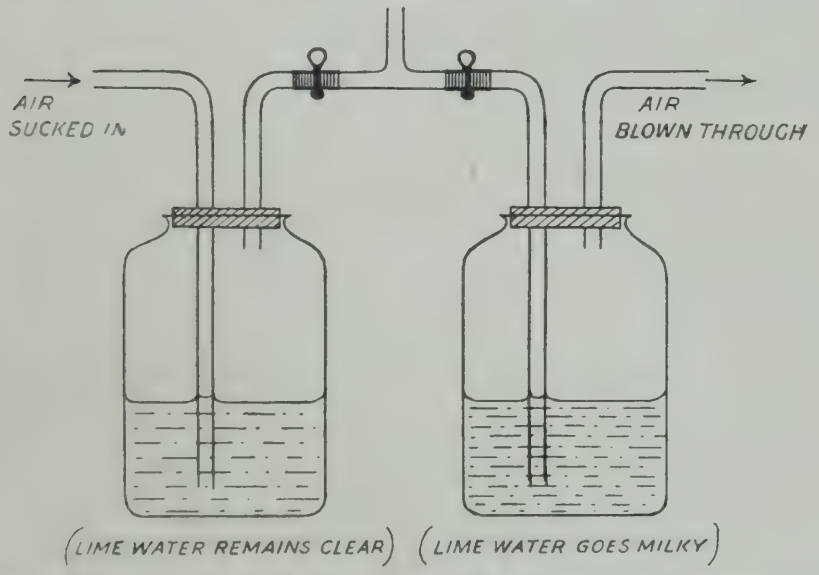


FIG. 16. APPARATUS TO SHOW HOW RESPIRED AIR DIFFERS FROM ORDINARY AIR

longer oxygen, since it will extinguish a flame. The jar is, in fact, now filled with *carbon oxide*, which is a gas. We usually call this gas carbon *di*-oxide, for on analysis it is found that the carbon has taken *twice* (*di*) as much oxygen as, from other chemical observations which need not concern us here, we might have expected.

If we pour a little lime-water into the jar of carbon dioxide and shake it up, the lime-water will turn milky. The milkiness is caused by the formation of thousands of tiny particles of a white solid—chalk. Lime-water is a

solution of lime in water, and when carbon dioxide acts upon it the lime and the carbon dioxide combine together to form chalk. We have here, therefore, a *test* for carbon dioxide. Now, we discovered that the air we breathe out will turn lime-water milky: hence it must contain carbon dioxide. Ordinary air, on the other hand, did not turn the lime-water milky in our experiment, so that it appears that there is no carbon dioxide in it.

How is it that carbon dioxide is formed inside us and expelled from our lungs when we breathe out? You will get a clue to this problem if you think of what happens to a piece of steak if it lies forgotten on a grid-iron over a hot fire: it becomes blackened or *charred.* In other words, *carbon* is produced, and that this carbon was in the steak originally could be shown by burning another piece of the same steak in a vessel containing pure oxygen; carbon dioxide would be formed, as could be proved by adding lime-water, which would be turned milky. Flesh, then, contains carbon, though not *free* carbon. It contains substances which, like carbon dioxide, are made partly of carbon and partly of other things. When any substance containing carbon is burnt in oxygen, carbon dioxide is formed, and the fact that carbon dioxide is present in expired breath would lead us to think that we, and animals in general, are slowly burning away in the oxygen of the air! This is just what is happening; we do not, however, burn away completely, because we eat food to make up for that part of our body which gets consumed. Although, so to speak, we have fires all the time, our cellars are not empty because we are continually having fresh supplies of coal.

Why do we Breathe? — When coal — which consists chiefly of carbon—is burnt, carbon dioxide is formed and at the same time a great deal of heat is given out. This heat may be used to keep us warm, or to make steam and thus to drive engines and do work. We breathe for similar

reasons. The slow burning of carbonaceous materials in our bodies keeps us warm, for heat is liberated in the process, and this heat also provides us with energy or ability to do work. The harder we work the more energy we want; thus, when we sprint for a hundred yards, our "engines" are doing a great deal of work. Hence we breathe much faster and so burn away more quickly—in other words, we get energy liberated at a greater rate.

There is a question which has almost certainly been on the tip of your tongue for some time. It is this: Since all animals breathe, and therefore form carbon dioxide which goes into the air, and since millions of tons of coal are burnt every week, forming more carbon dioxide, how is it that the oxygen in the air is not all used up, and why does not ordinary air turn lime-water milky? As far as the second part of the question is concerned, the reply is that air *does* turn lime-water milky in time, but only very slowly. There is, therefore, not a high proportion of carbon dioxide in the air, but there is *some.*

Analysis of air, carried out from year to year, shows, however, that the percentage of carbon dioxide in the atmosphere remains practically the same, namely, about 0 03, or 3 litres of carbon dioxide in 10,000 litres of air. This is a very strange fact, for, in view of the enormous quantity of carbon dioxide produced every day, we should expect the percentage of it in air to increase continuously. There is a very simple explanation. We shall consider the problem again in Chapter VII., but, in short, the solution is this: plants *feed* on carbon dioxide, and thus remove it from the air. Hence it does not go on accumulating, but is always being used up.

A Change of Air. Malaria.—When we are "out of sorts" or convalescing from an illness, the doctor often recommends us to have a "change of air." Climate, of course, does have a very marked effect upon health, hot and moist climates being especially injurious. At no very remote period,

however, men believed that many diseases were actually caused by "bad air," and one disease in particular was so firmly held to be produced by a poisonous atmosphere that it was actually called *malaria*, which is an Italian word meaning "bad air."

Malaria, which is a kind of fever, is a very serious plague, for in regions which are infested with it, such as the Terai at the foot of the Himalayas, it weakens practically the whole population as well as causing a great many deaths. In Italy, in India, and in many other countries, the sickness and mortality produced by malaria have been appalling. Thanks to science, however, we now know exactly how malaria is caused and how it spreads, with the result that we can take steps to prevent it—and prevention is much better than cure.

For the solution of this problem it is pleasant to think that our chief thanks are due to an Englishman, Sir Ronald Ross, whom we may justly regard as one of the greatest benefactors of the human race that the world has ever seen. The story is well worth telling, so let us begin at the beginning of it. On the 6th of November, 1880, Dr. Laveran, a French army surgeon in Algeria, examined a drop of blood from a malarial patient by means of a microscope. He observed that it contained a great number of tiny living things which had never been seen before. Further work showed that these minute animals were present in the blood of *all* persons suffering from malaria, while they could not be found in the blood of healthy people. It was therefore supposed that they were the *cause* of malaria, and hence they were named "malarial parasites," *parasite* meaning an animal which feeds on another living animal.

The next step in the investigation was to discover how these parasites got into the blood of the patient. This discovery, which was really the essential one, was made in 1895 by Sir Ronald Ross, who was then a major in the

Indian army. Sir Ronald found that when a certain kind of mosquito or gnat called *Anopheles* (see Fig. 17) sucked the blood of a malarial patient, the parasites got into the walls of the mosquito's stomach. There they underwent certain changes, and finally passed into the insect's salivary glands, i.e. those bags which produce the saliva or spittle in its mouth. When a mosquito suffering in this way bites a man, its biting apparatus, which is covered with saliva, naturally sends malarial parasites into his blood and he therefore soon becomes ill with malaria.

FIG. 17. MALARIA MOSQUITO [1]

Malaria is thus spread in the following way:

(i) Mosquitos of the *Anopheles* family suck the blood of people who have malaria.

(ii) The mosquitos themselves thus become infected with malarial parasites.

(iii) The parasites at length work their way into the salivary glands of the mosquitos.

(iv) The mosquitos bite healthy people and, in doing so, infect them with the parasites.

When the parasites get into the blood of a healthy person,

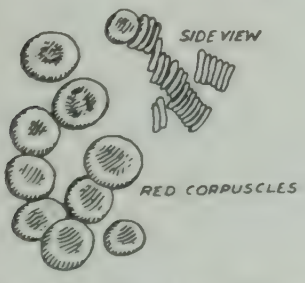


FIG. 18. HUMAN BLOOD UNDER THE MICROSCOPE

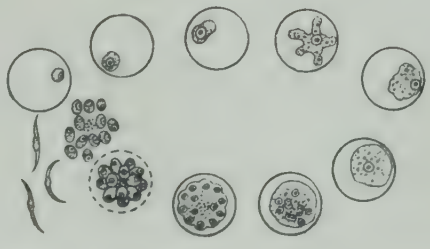


FIG. 19. MALARIAL PARASITES IN BLOOD

they grow and multiply at a great rate. If you look at some blood under a microscope, you will see that it consists of a clear liquid containing (*a*) little pieces of a white

[1] *From a drawing in the "Encyclopædia Britannica."*

jelly-like substance (the "white corpuscles") and (*b*) red discs (the "red corpuscles"), which often cling together and then look something like piles of coin (see Fig. 18). The malarial parasites get into the red corpuscles, which they destroy and turn into a black substance, as you can see if you look at the illustration (Fig. 19). At the same time they produce poisons, so that the illness of the patient is really due to two causes: (*a*) loss of red corpuscles, and (*b*) poisoning.

Prevention of Malaria.—In order to cure a malarial patient he is given large doses of quinine, but this remedy is not always successful. It would clearly be much better to prevent people from getting malaria than to try to cure them when they have got it. Now, until Sir Ronald Ross had shown how malaria was carried, doctors could take no measures to prevent the disease, for they did not know what they had to fight against. When the evil deeds of the mosquito were discovered, however, steps were immediately taken, first of all to make quite sure that no one could get malaria if he were not bitten by a mosquito, and secondly to destroy the mosquitos and thus put an end to their dangerous activities.

Several experiments were carried out on the first of these two points. In 1900, Drs. Sambon and Low, Signor Terzi and two Italian servants went to live for four months in one of the worst malarial districts in Italy. They fixed fine netting all over the windows and doors of the hut in which they lived, so that no mosquitos could get in. They did not get malaria, although the inhabitants all around them suffered from it very heavily. In order to make quite sure, Dr. Sambon and his friends caught some mosquitos and sent them in a box to a London hospital. Here they were allowed to bite some men who volunteered for the experiment, and the men so bitten quickly developed malaria. Hence Sir Ronald Ross's theory was confirmed.

The next step was to think of some way of killing

mosquitos. Now mosquitos breed in marshy and swampy places. Many of these were drained, and here the number of mosquitos was considerably lessened. Wherever this was done malaria became correspondingly less frequent, and in many places practically disappeared. Thus at Ismailia (Egypt), in 1900, there were 2250 cases of malaria out of a population of 6000. In 1905, after drainage had been carried out, there were only 37 cases, and most of those were people who had had the disease before and had not quite got rid of it.

In some places it is difficult to drain all the ponds and swamps where mosquitos breed, so a different method is adopted. For part of their life mosquitos live, in a somewhat grub-like form (the *larva*), under the surface of water. If this water is covered with paraffin, the larvæ (plural of *larva*) cannot develop and they finally die. The main points in the prevention of malaria are therefore as follows:

(i) Destroy mosquitos as far as possible.

(ii) Use mosquito nets to keep away those mosquitos which escape.

(iii) Keep malarial patients isolated so that mosquitos cannot bite them.

The succession of wet summers which we have recently experienced in England has caused a plague of mosquitos in this country. Fortunately there are only a few people here who are afflicted with malaria, so that up to the present we have not suffered. The danger, however, is a very real one, and everyone ought to do all he can to prevent mosquitos from breeding, otherwise we may regret too late.

Bacteria in Air.—We have seen that the "bad air," or "malaria," which was supposed to be the cause of the disease of the same name, has been cleared of the suspicions cast upon it. There are, however, millions of tiny plants in ordinary air, some of which are capable of causing disease if they get a hold upon us. Those minute plants are called *bacteria*, and they are far too small to be seen with the

naked eye. Many of them are only about one-thousandth of a millimetre in diameter, so that to observe them we have to use very powerful microscopes. In order to get some bacteria to look at, chop up a little hay and pour about half a pint of boiling water on to it. Stir up and leave for a few days. Then take a drop of the liquid, put it on to a microscope slide and look at it with the highest power of the microscope. You will see thousands of tiny rod-shaped objects; these are bacteria of a kind known as *Bacillus subtilis* (see Fig. 20).

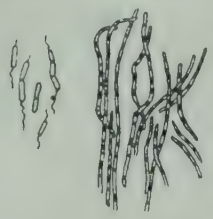


FIG. 20. BACILLUS SUBTILIS, HIGHLY MAGNIFIED [1]

Very many different sorts of bacteria are known, some of which you will see in Fig. 21. Some kinds are round, others are rod-shaped, others look like commas and others again like drum-sticks. One of the most remarkable things about them is the speed with which they multiply if they

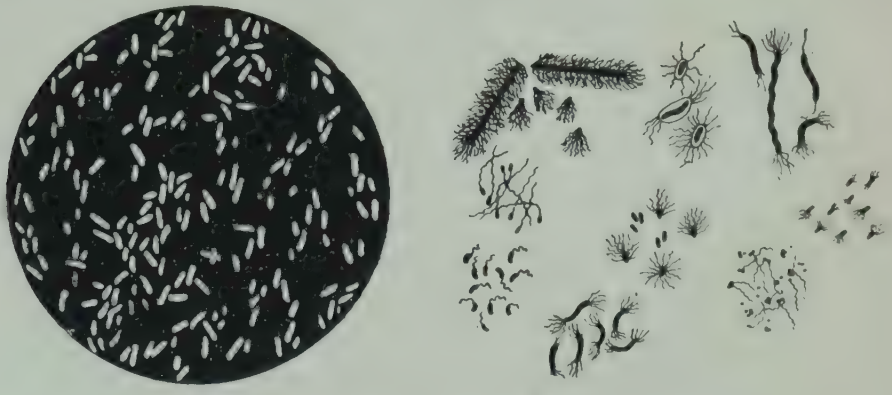


FIG. 21. DIFFERENT VARIETIES OF BACTERIA [1]

have plenty of food and are kept warm and away from light. Under good conditions, each bacterium may divide into two every twenty minutes or so! Let us see how many we should get by 10 p.m. if we started with 1 bacterium at noon on the same day. At 12.20 we should have 2;

[1] *From drawings in the "Encyclopædia Britannica."*

at 12.40 each of these would have divided into 2, so that we should have 4; at 1 o'clock we should have 8, and so on as in the following table:

Time	No. of Bacteria
12 noon	1
12.20 p.m.	2
12.40	4
1.0	8
1.20	16
1.40	32
2.0	64
2.20	128
2.40	256
3.0	512
3.20	1,024
3.40	2,048
4.0	4,096
4.20	8,192
4.40	16,384
5.0	32,768
5.20	65,536
5.40	131,072
6.0	262,144
6.20	524,288
6.40	1,048,576
7.0	2,097,152
7.20	4,194,304
7.40	8,388,608
8.0	16,777,216
8.20	33,554,432
8.40	67,108,864
9.0	134,217,728
9.20	268,435,456
9.40	536,870,912
10.0	1,073,741,824

That is, under very favourable conditions, 1 bacterium in 10 hours could give rise to no less than 1073 millions! In a week, the number would have increased so much that the total weight of the bacteria would not be far short of that of the whole earth!

Fortunately, conditions are never so favourable as this in actual life. In the first place, there is not enough food

for the bacteria. Secondly, they do not like sunlight, which may kill them. Thirdly, the average temperature is not high enough to suit them: they like blood-temperature (37·5° C. or 98·4° F.) best of all. And fourthly, bacteria—like all other living things—produce waste material which, if it collects around them, poisons them.

Nevertheless, bacteria do thrive and swarm enormously, and we can easily show that there are plenty of them in the air in the following way. We take two flat glass dishes, with covers (see Fig. 22), and heat them in an oven for about twenty minutes, in order to make sure that any bacteria they may contain are killed. We then pour into each of them a little melted agar jelly which has itself been previously heated in steam to kill any bacteria which may be in it. Agar jelly is made from certain kinds of seaweed. When it has been treated in this way it is said to be *sterilised*. Tubes of sterilised agar jelly can be bought from any large chemist's shop. To melt the jelly, the tubes are placed in a beaker of water and the latter is then heated. When the water boils the jelly melts.

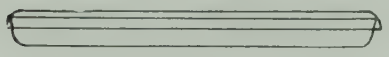


FIG. 22. DISH FOR GROWING BACTERIA

We then take the glass dishes and, cautiously lifting the lids a little way, we pour the agar jelly in. The lids are immediately replaced and the jelly is allowed to set. At present, then, we have sterilised agar in sterilised dishes, so that there are no bacteria in either dish. Next we take the lid off one dish for about ten minutes, so that if there are any bacteria in the air some will have a chance of settling in the agar. Afterwards we replace the lid and then set both dishes in the dark in a fairly warm place—say a warm cupboard near the fire—for four or five days.

At the end of this time we shall notice that the agar which was not exposed to the air is just as it was originally, but that that which was exposed is now covered with a

number of yellowish patches (see Fig. 23). If we take a little of one of these patches on the end of a needle, stir it up with a drop of water on a microscope slide and then look at it under the microscope, we shall see that it consists of thousands of bacteria, all of the same sort.

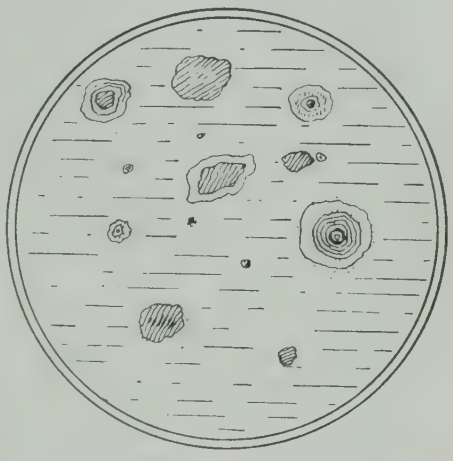


Fig. 23. Bacterial Colonies Growing on Jelly

The patches are, in fact, *colonies* of bacteria. Each of them has grown from one bacterium during the time the plate has been in the warm cupboard, so that if we count the number of colonies we shall know how many bacteria got into the agar in the dish during the time it was exposed to the air. That these really did come from the air is proved by the fact that the other dish, which was treated in exactly the same way except for the exposure, contains no colonies whatever.

It is interesting to repeat this experiment with saliva from the mouth and with soil from the sole of a boot. In these cases, a little of the soil or saliva is put into the tube of melted agar which has been allowed to cool to about 45° C. after having been placed in the boiling water for the agar to melt. The tube is shaken round so as to cause a thorough mixing and the agar is then poured out into a sterilised dish. This is kept in a warm cupboard for three days. You may be surprised at the wonderful variety of bacteria you are carrying about in your mouth!

Bacteria and Disease.—Many diseases are caused by bacteria which get through the walls of the throat and mouth and hence into the blood. Here they find splendid conditions—warmth, darkness and plenty of food. They

therefore multiply exceedingly, and the waste products to which they give rise poison us and make us ill. Common diseases caused by bacteria are consumption, pneumonia, bubonic plague, cholera and anthrax. The latter is a disease of pigs and sheep, etc., but it may affect men, and if it does it is generally fatal. Shaving-brushes made from pig's bristles sometimes contain anthrax germs, and these may get into the blood through a cut in the skin. Many manufacturers, therefore, now give with their shaving-brushes a guarantee of freedom from anthrax.

Lock-jaw, or *tetanus*, is another terrible disease caused by bacteria—the *Bacillus tetani*—commonly present in soil and like a drum-stick in shape.

Fighting Bacteria.—When bacteria get into the blood they do not have it all their own way. The white corpuscles, mentioned on p. 51, attack them at once and begin to eat them up, so that there is a tremendous battle. If the corpuscles win, the patient recovers. If not, one of two things may happen. The poisonous waste materials which the bacteria produce are poisonous both to the patient and to the bacteria themselves. Sometimes the patient is poisoned before the bacteria, in which case he dies. In other cases, the bacteria get poisoned first and so die off and the patient may get better. Nature, moreover, looks after us in another way, and does not leave the corpuscles to fight the battle alone. She causes our bodies to produce peculiar substances which poison the bacteria and help to neutralise the effect of the injurious waste materials formed by the bacteria. These substances are known as *anti-toxins* ("against the poisons").

Outside the body we can fight disease-bacteria by disinfection, i.e. by using substances which will kill them. Carbolic acid and formalin are common disinfectants, while to sterilise cuts and scrapes on the skin a solution of iodine is very satisfactory.

Useful Bacteria.—We should be doing bacteria an

injustice if we thought of them only as harmful. There are many very useful kinds which render man good service. Thus, decay of dead bodies of plants and animals is brought about by bacteria, and in this way the earth is cleared of refuse which might otherwise accumulate. Moreover, in the process of decay the substances of which the dead bodies are made are converted into plant food which, in the soil, serves to nourish living plants. The souring of wine, again, which gives us vinegar, is brought about by a special kind of bacterium, so that you see bacteria are both useful and harmful to man. What we have to do is to help the useful ones and to try to destroy those that are harmful.

Draughts and Ventilation.—What we have learnt about bacteria will help us to understand the cause of "colds." People who like calculations have reckoned that the cost to the country through loss of work caused by colds amounts to several million pounds a year. Quite apart from this, however, colds are extremely unpleasant and often lead to far more serious illnesses. Now, most people believe that sitting in a draught or getting wet feet will very probably result in a cold; they therefore maintain that draughts and exposure are the *causes* of a cold. This argument, if we examine it a little closely, is seen to be faulty, and we may perhaps understand where the flaw lies if we take another example. If a man sits on a railway track, he will probably be killed, but it is not correct to say that the *cause* of his death is the fact that he sat on the line. The actual cause of death is the blow which the express gives him. Sitting on the line merely put the man into such a position that the cause of death could be brought into action.

The same kind of thing is true about the relation between draughts and colds. The ordinary cold is an illness caused by bacteria. These bacteria are very common indeed, and, as a matter of fact, we probably always have a few of

them in our mouths and throats. Generally, however, they are unable to make much headway, and we remain well. But if we sit in a draught or get our feet wet, our body becomes chilled and is not able to put up such a good fight. The cold-germs take advantage of this temporary weakness and sometimes manage to gain a foothold: not long afterwards we begin to shiver and realise that we have "caught cold."

Very often we sit in a draught and enjoy it. At other times we feel uncomfortable at once. In the latter case, it is very probable that we have caught cold before and that the illness is just beginning to manifest itself. The poisons which the bacteria produce make us very sensitive to changes of temperature; hence the feeling of discomfort when the draught blows upon us.

Bacteria of all sorts are killed by strong light and many of them do not like oxygen. Hence fresh air and sunshine will go far to keep us healthy even from this cause alone. They do more, however. Fresh air helps to purify our blood and to make us feel fit and vigorous. And since bacteria cannot overcome us without a struggle, the fitter we are the less chance they will have. Sunlight, again, besides killing bacteria, helps wonderfully to tone up our whole system. Scientists have recently discovered that, to be healthy, a human being must have in his body small quantities of mysterious substances called *vitamines*. These vitamines are present in fresh fruit and vegetables, in cod-liver oil, in fresh milk and butter, and in other foodstuffs, and we usually get enough of them without taking any particular care in choosing our food. Modern food, however, is very largely preserved or tinned or manufactured, and in these processes the vitamines may be, and generally are, destroyed. A deficiency of vitamines in our normal food may therefore occur, but as long as we get plenty of sunshine this does not matter much, since the light of the sun seems to be able either to produce

vitamines in our body or else to enable us to do without them to some extent.

In a dull and sunless climate such as that of England, we cannot get much assistance from the sun, so that we ought always to make the most of the opportunities that do arise. We ought also to eat green vegetables, preferably uncooked ones, such as lettuce, and other things in which vitamines are found, so as to make up for the absence of sunshine. If you don't like cod-liver oil, get as much sunshine as you can. They have the same effect!

Since, as we have learned above, draughts may chill us and so predispose us to catching cold, and since, on the other hand, fresh air is very necessary to our health, the problem of how best to ventilate our houses, and to warm them, becomes of great importance. What we have to aim at is to get a constant supply of fresh air in the rooms, without causing a draught and, in cold weather, without chilling the rooms.

Warm air is lighter than cold air and therefore rises, just as a balloon, filled with the light gas hydrogen, will rise. Hence, if there is a fire in the room, the hot air passes up the chimney and more air rushes in through the window or under the door in order to make up for that which is lost. If the air comes in under the door, there will be a draught along the floor, and therefore our feet will get cold and we shall soon feel cold all over. The best way to allow the cold air to enter is through a ventilator which directs it *upwards*, so that it has to mix with the warm air gradually and thus cannot chill us by striking us directly. A ventilator of this kind is shown in Fig. 24.

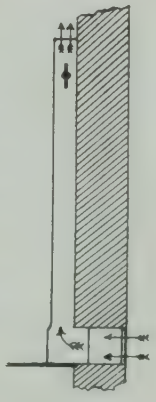


FIG. 24. A VENTILATOR[1]

If a window is open at the top cold air will flow in there, and, being heavier than the warmer air of the room, will

[1] *From a drawing in the "Encyclopædia Britannica."*

descend as a cold stream upon our heads in a very uncomfortable way. The best way of using a window as a ventilator is to open it a little at the top and then to place a piece of board so as to block up the opening. Air will then have to rise through the space between the two sashes and will thus mix with the air in the room gradually and not cause a draught. In a bedroom, both the top and the bottom sashes should be open. Used air then goes out through the top and fresh air comes in through the bottom. If we are warmly covered and not directly underneath the window, we shall not be chilled and shall feel all the better for sleeping in the fresh air.

Warming a Room.—It has been found that as long as a man keeps his feet warm he generally feels warm all over. Hence, in making arrangements for heating a room, we ought to see that the floor is warmed. In England, where —in private houses at least—open coal-fires are used, the floor gets warmed quite sufficiently. This is one of the reasons why one feels so much more comfortable by an open fire than in a room heated by those ugly and depressing objects called radiators. Another advantage of the open fire is that it ventilates the room much better than do radiators. A third—which is perhaps the chief of all—is that the sight of a blazing fire on a cold night makes us feel glad to be alive: and feeling glad to be alive is one of the best ways of keeping healthy! Coal-fires, of course, are wasteful, for much of the heat goes up the chimney. They are responsible, too, for sending a good deal of smoke into the atmosphere and thus helping to cause fogs. But, on balance, it is probable that the coal-fire would win in most people's estimation. To them it is not merely a source of heat: it is a friend. It is difficult to imagine fire-worshippers bowing down to a radiator.

Waves in Air.—When you throw a stone into the middle of a still pond, you notice that waves spread out in circles until they reach the bank. The water as a whole does not

move, however, as you may discover by putting a cork half-way between the centre of the pond and the edge: the cork bobs up and down as the waves pass it, but it remains in practically the same position as that in which you put it. The waves travel through the water; the water itself stays in the same place.

Another observation which you must have made is the following. Standing on a hill and watching a man in the valley beneath chopping wood, you have noticed that the sound of each blow reached you some little time after you saw the axe strike the wood. Now you see the axe because of the rays of light which pass from it into your eye, and it follows that sound does not travel as fast as light. What carries the sound to your ear? We can answer this question by making an experiment, which, you remember, is the only satisfactory way in science.

Let us take an electric bell and put it on a pad of cotton-wool under the receiver of an air-pump (Fig. 25). By turning on the current we can start it ringing. We then begin to pump the air out of the receiver, and we notice that the sound gradually becomes fainter and fainter until at last we can hear it no longer. Yet the bell is still ringing, for we can see the hammer vibrating as vigorously as ever. When we let air into the receiver again the sound comes to our ears once more, faint at first and then as loud as before.

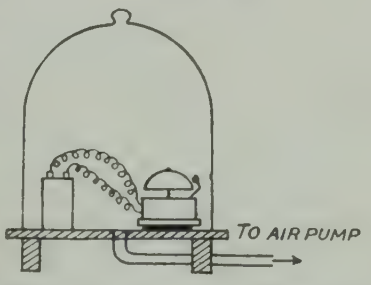


FIG. 25. ELECTRIC BELL IN RECEIVER OF AIR-PUMP

This experiment shows us that sound is carried by the air, and the behaviour of the water of the pond when the stone was dropped into it helps us to understand *how* the air carries sound. When the hammer of the bell strikes the gong, the latter vibrates, i.e. moves backwards and forwards very quickly. In doing so, it causes waves in the

air around, and these waves travel outwards in circles until at last they strike the drum of our ear. This in turn vibrates, and the nerves which are connected to it carry the message to our brain: in other words, we *hear* the sound.

Now the waves in the pond took an appreciable time to reach the bank; and in the same way sound waves, although they travel quickly, move at a rate which can be easily measured. Suppose, for example, you stood a mile away from a man with a pistol, and that you both had watches which showed exactly the same time. At a given moment he could fire his pistol and you could note the time at which you heard the sound. Then the number of seconds which had elapsed after the pistol was fired and before you heard the report would be the time taken for sound to travel a mile. You would find that time to be about five seconds. Exact measurement has shown that sound waves travel in air at about 1100 feet per second.

This gives us a way of finding out how far distant a flash of lightning occurred during a thunderstorm. If, for example, you heard the thunder ten seconds after seeing the flash, you would know that the latter occurred about 11,000 feet—about two miles—away.

The fact that sound travels in waves through the air enables us to explain another curious fact. When you stand on the platform of a station and watch the Cornish Riviera Express dash through, you notice that the whistle becomes shriller and shriller as the train approaches, and becomes less and less shrill as she gets farther away from you. Now, the more sound waves that strike the ear in a given time, the shriller (*not the louder*) seems the sound. If the engine starts whistling when a quarter of a mile away, it will send out sound waves from that spot. If it were stationary it would go on sending out these waves and they would reach your ear regularly; you would therefore hear a whistle all on the same note. But the engine is approaching you rapidly; hence the sound waves it sends out at one

instant have not so far to travel as those it sent out the instant before. They therefore reach you more quickly, and the result is that more and more waves strike your ear each instant as the train gets nearer. Your brain therefore imagines that the whistle is getting shriller and shriller, whereas, as a matter of fact, it is really on the same note all the time. To the engine-driver, who is travelling at the same speed as the whistle, the note does not vary, but if, as he was on his engine, a stationary engine began to whistle, he would think that the note of the latter got higher and higher as he came nearer to it, although to a man standing by the stationary engine there would be no change.

In the same way, after the train has passed you, less and less waves reach your ear each instant. The note therefore appears to become lower and lower.

Sir William Ramsay and Helium.—In this chapter we have learnt a great deal about air, and have seen that Aristotle was wrong when he believed it to be an element. We have not yet come to the end of the story, however. When chemists had shown that air consists of a mixture of oxygen, nitrogen, carbon dioxide and water vapour, they thought that they had completed its analysis. Yet if they had remembered an experiment made by Cavendish towards the end of the eighteenth century, they might not have felt as confident. Cavendish tells us that he was passing electric sparks through some air in a glass jar to see what happened. He found that a brown gas was formed, which we now call *nitrogen peroxide* and know to consist of oxygen and nitrogen. Cavendish found that this gas would dissolve in a solution of caustic potash, and could therefore be removed from the remaining air. After a time, although he continued to pass the sparks, he found that the brown fumes were no longer found. He rightly concluded that this was because all the oxygen had been used up. He therefore added a few bubbles of oxygen and

observed that, on passing the sparks, the brown fumes were again formed. Since the oxygen and nitrogen were both being used up, and converted into the brown gas which he absorbed in caustic potash solution, the volume of the residual gas was getting smaller and smaller all the time. He continued to add a small quantity of oxygen from time to time, but discovered at length, when the volume of residual gas was only about $\frac{1}{120}$ of the original volume of air, that he could no longer obtain any brown fumes, even when he added plenty of oxygen and sparked the mixture for a long time. He seems to have left the experiment at that stage, but he probably guessed that this small bubble of gas, about $\frac{1}{120}$ of the original volume of air, was not nitrogen, for he says, "If there is any part of the [nitrogen] of our atmosphere which differs from the rest . . . we may safely conclude that it is not more than $\frac{1}{120}$ part of the whole."

For over a hundred years Cavendish's observation was forgotten. Then, in 1894, Lord Rayleigh was engaged on experiments to find, as exactly as possible, the weight of one litre of pure nitrogen. For this purpose, he obtained various samples of nitrogen from different sources. One he got by absorbing all the oxygen, carbon dioxide and water vapour from air, thus obtaining, as he supposed, pure nitrogen. Another he obtained from a substance known as ammonium nitrite, which when heated gives off nitrogen. Great was his surprise to find that the nitrogen obtained from air was always slightly heavier (about 0·5 per cent.) than that obtained from ammonium nitrite. He repeated the experiment several times and always with the same result. He knew that the difference could not be due to a mistake on his part, for he had conducted all his measurements with very great care and was certain that, if he had made an error, it could not be as much as 0·5 per cent. Besides, in repeated trials, the difference was always about the same, whereas if it had been due to a mistake

in the experiment, it would probably not have been the same each time.

Lord Rayleigh then remembered Cavendish's observation, and, thinking that perhaps here was a clue to his strange results, he repeated the experiment which Cavendish had carried out and found that the great eighteenth-century chemist was right. There was, indeed, a bubble of gas left which was certainly not nitrogen, for it refused to form brown fumes when sparked with oxygen. Rayleigh then came to the following conclusion: since one litre of atmospheric nitrogen is always about 0·5 per cent. heavier than one litre of nitrogen made from ammonium nitrite, *there must be another gas present in the air,* and the bubble which Cavendish obtained—about $\frac{1}{120}$ of the volume of the air he had started with—must consist of this gas. Here was a thrilling discovery! Air, that common substance which chemists had been investigating for years and years, and about which they fancied they knew all there was worth knowing, had secrets which they had never suspected.

Rayleigh next began experiments, in collaboration with Sir William Ramsay, to obtain the new gas in larger quantities. This was done by passing air (i) through caustic potash solution, to remove the carbon dioxide; (ii) through sulphuric acid, to remove the water vapour; (iii) over red-hot copper, which combined with the oxygen and so removed it; and finally (iv) over red-hot magnesium, which combined with the nitrogen. The remaining gas—the new gas—was found to be entirely different from all other known substances, for it would not combine with any other element or take part in any chemical reaction whatever. It was therefore called *argon,* from the Greek word for *lazy.*

The discovery of argon naturally led chemists to say, "Well, the atmosphere is apparently not so simple as we had thought. How do we know that we have not overlooked other gases besides argon?" Further experiments

were carried out to provide an answer to this question, and another romantic episode occurred. In 1868, by means of an instrument called the *spectroscope*, the great astronomer Sir Norman Lockyer had shown that there is in the sun an element which at that time had not been discovered upon the earth. The Greek word for *sun* is *helios*, so he called this new element *helium*. In 1894 Ramsay was investigating the gases given off when a mineral called *cleveite* was heated, and he found that, although the main constituent of these gases was nitrogen, there was present also, in small quantities, a gas which no chemist had ever obtained before. He was excited to find that, in its chemical properties, this gas was almost exactly similar to argon, that is, it was extremely lazy and would not take part in any chemical reaction. On examining it with the spectroscope he discovered—and you may imagine his joy—that it was no other than that element *helium* which Sir Norman Lockyer had detected on the sun twenty-six years before!

Rayleigh and Ramsay then went on to examine air very closely to see if they could find anything else. The way they set to work was this. They liquefied several tons of air (see p. 34) and then let it come to the boil very gradually. You will remember that the nitrogen and oxygen of air can be separated from one another in this way (p. 46), since they boil at different temperatures. By conducting the experiment very carefully indeed, Rayleigh and Ramsay obtained, not merely nitrogen and oxygen, but also argon—which they expected, of course, after their previous work. They collected all the argon separately, liquefied it once more, and let it come to the boil by itself again, very cautiously. They then found that the argon was not pure, but contained other gases as well, one of which was helium. The remaining ones, three in number, they called *neon* ("new"), *krypton* ("hidden") and *xenon* ("the stranger").

Argon, helium, neon, krypton and xenon form altogether about 1 per cent. of the air by volume. They all resemble one another in being extremely unreactive substances and are therefore known as the *inactive gases*. Perhaps you will say, "Yes, the story of their discovery is very thrilling, but are they of any practical use?" Well, at first they were not, but nowadays helium, argon and neon are very important in everyday life. Helium is a very light gas (it is only twice as heavy as hydrogen, the lightest of all substances), and as it is quite non-inflammable it is used to fill airships. There is too little of it in the air (1 litre in every 250,000 litres) to make its abstraction from air commercially worth while, but fortunately it has been discovered that the gases of certain gas-wells (e.g. at Medicine Hat, in Canada, and in Kansas, U.S.A.) contain as much as 1 per cent. of helium. From these gases it can easily be obtained, and the United States Government has set up special factories for the purpose. The ever-present danger with airships filled with hydrogen is that of fire; when they are filled with helium this danger is no longer present. So you see that Cavendish, Lockyer, Rayleigh and Ramsay, although they were working for the sheer love of knowledge, have indirectly helped

MICHAEL FARADAY

to save many lives and to aid man in his conquest of the air.

Neon and argon, again, are now extensively used for filling electric lamps. So, even if a scientific discovery appears at first to have no practical value, it may in a few years' time play a very important part in our daily lives. Gladstone, one of the most famous of English Prime Ministers, could never understand the importance of scientific discovery, and the great scientist Faraday, to whom he was talking one day, knew this. Faraday had just been explaining an important new discovery in science, and all that Gladstone said was, "But, after all, what use is it?" Faraday, with a witty contempt, replied, "Why, sir, there is every probability that you will soon be able to tax it!" It was Faraday, too, who silenced a lady who remarked, "But, Professor Faraday, even if this is so, what is the use of it?" with the retort, "Madam, will you tell me the use of a new-born child?"

CHAPTER IV

WATER

Is Water an Element?—We know that Aristotle thought that water was an element, and that for many centuries all men of science agreed with him. But we should not be doing as he would have liked us to do if we believed all he said without making experiments for ourselves. Now, if water is really an element, we should find it quite impossible to split water up into two or more other substances. Yet this is a task which we can carry out very easily.

Passing Electricity through Water.—Suppose we take an electric battery, consisting of two or three accumulators such as are quite familiar to you from your knowledge of a wireless set. Let us connect a wire to each terminal and dip

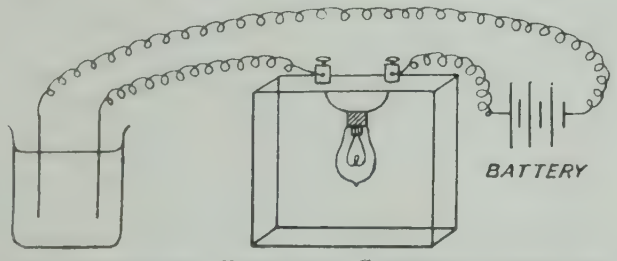


FIG. 26. PASSING THE ELECTRIC CURRENT THROUGH WATER

the other ends of the wires into some distilled water in a beaker. We shall find that apparently nothing is happening. Can we be quite certain, however, that the electric current is really going through the water? Merely by looking at the apparatus, we cannot. Suppose, however, we make a slight improvement in the arrangement, by connecting up a small electric lamp in the way shown in the figure (Fig. 26). If the lamp lights, we shall know that the current

is able to flow through the water. When we try the experiment, however, we notice that the lamp does not light up. Hence we can conclude that electricity cannot pass through distilled water.

Now let us dissolve a pinch of salt in the water. When we do this the lamp lights at once. If, instead of using pure water at first we had used sea-water, we should have found that the current passed immediately, because, as everyone knows, sea-water contains a good deal of salt. Further on in this book (Chapter VII.) we shall talk again about the passage of electricity through water, but here it is sufficient for our purpose to know that, while absolutely *pure* water will not allow the electric current to pass through it, water with just a little salt in it will do so.

What happens when Electricity passes through Water?—When the electric current is allowed to pass through slightly salty water, bubbles of gas begin to come off at the end of each wire. This interesting fact was first noticed by two chemists named Nicholson and Carlisle, in 1802.

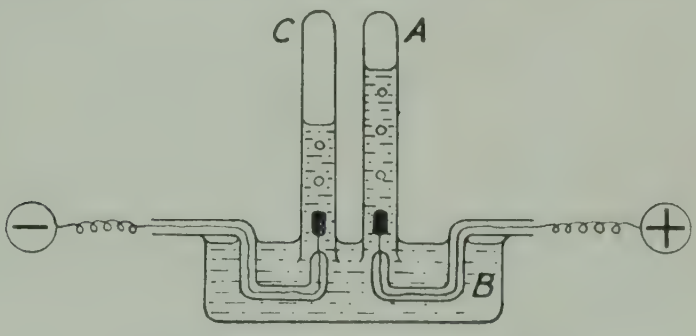


FIG. 27. ELECTROLYSIS OF WATER

They were working with an electric battery and accidentally the ends of the wires dropped into a small pool of rather dirty water on the bench. When they noticed the bubbles of gas they were keenly interested, and tried to find out what the gases were.

With the apparatus shown in Fig. 27 we can repeat

Nicholson and Carlisle's experiment very conveniently. The salt-water is placed in the basin B, and the two upright tubes, A and C, are also filled with it. The ends of the wires to the battery are connected to two pieces of platinum sheet or foil, and the wires themselves are not allowed to come into contact with the water. This is because, if they are made of copper (as they generally are), they soon get eaten away; platinum, on the other hand, is a very resistant metal and will remain bright. The terminals of the battery are marked + and − (positive and negative) respectively. Let us connect the platinum plate in tube A to the positive terminal and that in tube C to the negative. The two plates together we call the *electrodes*; that which is connected to the positive terminal of the battery is called the *anode*, and the other, which is connected to the negative terminal, is called the *cathode*.

When the current is switched on, the bubbles of gas which are set free at the electrodes rise to the tops of the tubes and collect there. The first thing which we notice is that twice as much gas comes off from the cathode as from the anode. Both gases are colourless, and it is clear that neither of them can be soluble (able to dissolve) in water, otherwise, of course, they would not remain outside the water at the top. What are these gases, and where do they come from? A gas with which we have already become acquainted is oxygen, and we know that one of the properties of this gas is that it will relight a glowing splint. If we test the gases obtained in the above experiment with a glowing splint, we find that the gas which has come off at the *anode* will relight the splint. This leads us to believe that it is oxygen. We could make quite sure by finding out whether it will allow iron to rust in it, and by carrying out those other experiments which we have previously done with oxygen. We should find that the gas from the anode was in all respects identical with oxygen; in fact, it is oxygen.

If the gas which has come from the cathode is transferred to a test-tube and a lighted taper is then applied to it, it will burn—probably with a slight explosion. It is therefore very different from oxygen, which does not burn. This new gas we call *hydrogen*. We shall learn more about it later. Meanwhile we have discovered that, when the electric current is passed through water, two gases are produced, namely hydrogen at the cathode and oxygen at the anode, and that the volume of the hydrogen is twice that of the oxygen.

Where do the Oxygen and the Hydrogen come from?—The next question we have to consider is where the hydrogen and the oxygen come from. Well, there are only two possible sources, namely, the water itself and the salt which we had to dissolve in the water to make the latter conduct the electric current. It is easy to find whether the gases come from the salt or not in the following way. Suppose, in an experiment of this kind, we *weighed* the salt before we put it into the water. Then, if the gases come from the salt, it is clear that the latter will be wholly or partly destroyed during the experiment. In other words, there will not be as much salt left afterwards as there was to begin with. To find out how much there is left, all we need do is to take the remaining liquid and boil it until all the water has been evaporated and the salt remains. The salt can then be weighed. In experiments of this kind it has always been found that there is just as much salt left at the end as was put in at the beginning. It follows that the hydrogen and oxygen could not have come from the salt. But since they must have come either from the salt or from the water, and they did not come from the salt, therefore they must have come from the water. Some of the water, in fact, has been *analysed*, or split up, into hydrogen and oxygen.

Water is not an Element.—Aristotle was thus wrong when he considered water to be an element. We have seen

that it can be split up into hydrogen and oxygen, and is therefore not a simple or elementary substance but a compound. Now, if we can split water up into hydrogen and oxygen, it ought to be possible to *make* water by causing hydrogen and oxygen to combine. Is it likely that these two gases will combine together? Certainly, for oxygen is a gas which allows things to burn in it very readily, while hydrogen itself burns very easily. We already know how to get as much oxygen as we want; let us now turn aside for a moment to study hydrogen and its properties.

Hydrogen.—Although hydrogen can be obtained from water by passing the electric current through the latter, there is a much more convenient way of getting it. Sulphuric acid, sometimes known as *oil of vitriol*, contains a good deal of hydrogen, and it so happens that, when the

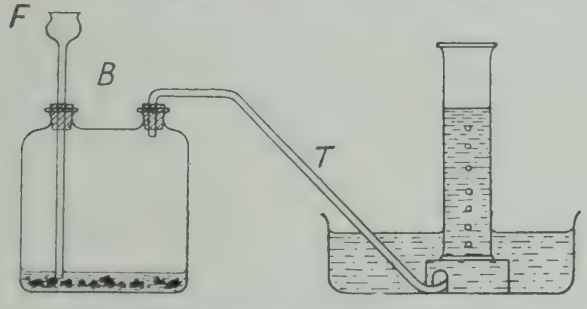


FIG. 28. PREPARATION OF HYDROGEN

acid is poured upon zinc, the zinc acts upon the acid and turns out the hydrogen, which comes off as a gas. The experiment is very easy to carry out, but sulphuric acid is a dangerous substance when pure, since it causes very bad burns if dropped upon the skin. Hence we do not use the pure or concentrated acid, but the *dilute* acid, that is, the acid weakened by having been mixed with water. There is another reason for using the dilute acid, namely, that zinc does not act at all readily upon the concentrated acid.

The apparatus generally employed for the preparation of hydrogen by this method is shown in Fig. 28.

The zinc, in the form of small granules or lumps, is placed in the two-necked bottle B, and is just covered by a layer of water. The dilute sulphuric acid is then poured down through the funnel F, the lower end of which dips under the surface of the water (this is to prevent the hydrogen from escaping through the funnel). As soon as the acid reaches the zinc there is a vigorous bubbling, or effervescence; the zinc dissolves and hydrogen comes off. Bubbles of gas soon begin to appear at the end of the tube T in the trough; these, however, are not at first hydrogen, but air. The bottle and tube were of course full of air to begin with, and as the hydrogen comes off it drives the air before it. After some time, all the air is driven over and the bubbles of gas which now come off in the trough are hydrogen. We now fill some gas-jars with water and invert them over the end of the delivery tube T; the bubbles of hydrogen rise into the jar, and soon fill it by displacing the water. When one is full, we replace it by another, and so on until we have collected sufficient hydrogen for our purpose.

If enough acid has been used, and the action allowed to go on for a sufficient time, it will be found that the zinc has all dissolved. There may be a few black specks floating about in the liquid, but these are not zinc: they are bits of carbon which were contained in the zinc as an impurity. If the clear liquid is filtered they will be left behind. After filtration the liquid should be evaporated in a basin. Presently a crust will begin to form around the edge, and, if the liquid is then set aside to cool, beautiful colourless needle-like crystals will form. These are called *zinc sulphate*, or white vitriol. We can, in fact, represent the action that takes place when zinc is dissolved in dilute sulphuric acid in the following way:

Zinc + sulphuric acid = zinc sulphate + hydrogen

Sulphuric acid is composed of hydrogen, sulphur (brimstone) and oxygen. When it is acted upon by zinc, the zinc takes the place of the hydrogen, and zinc sulphate, composed of zinc, sulphur and oxygen, is left:

Zinc	+	Hydrogen	Sulphur & Oxygen	=	Zinc	Sulphur & Oxygen	+	Hydrogen
		Sulphuric acid			Zinc sulphate			

Properties of Hydrogen.—One of the most remarkable properties of hydrogen is its extreme lightness. Hydrogen is much lighter than air, so that if we hold an open jar of hydrogen with its mouth upwards the hydrogen immediately escapes—just as if we held a jar full of corks mouth upwards under water the corks would immediately float up out of the jar. Hence, to keep a jar of hydrogen full of the gas, we must either cover its mouth with a well-fitting glass plate or else hold the jar upside down!

You can easily try for yourselves the following experiments with hydrogen:

(i) Hold a jar of the gas upside down and thrust a lighted taper up into it. You will notice that the hydrogen burns at the mouth of the jar, but that the taper itself is extinguished. Hydrogen therefore differs from oxygen, for oxygen will not itself burn, but will allow things to burn in it.

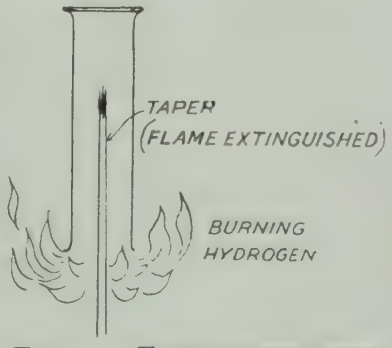


FIG. 29. EXPERIMENT WITH HYDROGEN

(ii) Take another jar and, holding it mouth upwards, remove the glass plate. After a few seconds, see if the gas left in the jar will burn. If it does not, it is clear that the hydrogen has escaped and is therefore lighter than air.

(iii) In your left hand hold, upside down, an empty gas-jar (i.e. really a jar full of air). With your right hand

bring a jar of hydrogen underneath the jar of air as shown in Fig. 30.

After a short time apply a lighted taper to each jar separately. You will find that the jar which originally contained the hydrogen no longer contains it; the gas in the other jar, however, burns—probably with a slight explosion. In other words, you have poured hydrogen *upwards* from one jar to another.

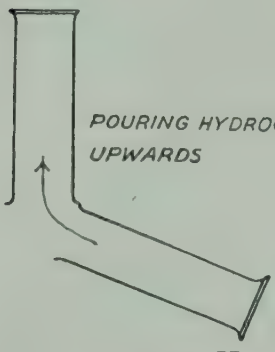


Fig. 30. Pouring Hydrogen Upwards

The extreme lightness of hydrogen has caused it to be used for filling balloons and airships. One serious drawback, however, is that hydrogen is so inflammable: a circumstance which has been responsible for many serious accidents. A spark from the motor, or a shell from the enemy, may set the hydrogen in an airship ablaze in a moment, and then disaster is bound to follow. The gas helium, you will remember, is now used where possible instead of hydrogen, since, although it is not so light as hydrogen and therefore cannot raise so heavy a weight, it is absolutely non-inflammable, and therefore the airmen do not have to dread the constant risk of fire.

Exploding a Mixture of Hydrogen and Oxygen.—If hydrogen burns so well in ordinary air, which contains only a comparatively small proportion of oxygen, what will it do in pure oxygen? This is an interesting experiment to make, and it can be done quite safely in the following way. Fill a gas-jar, at the trough, to the extent of two-thirds with hydrogen. Then pass in oxygen until the jar is quite full. Place the jar on the bench, remove the glass plate, and, using a long taper, apply a flame to the mouth. A loud explosion occurs; in other words, the hydrogen and the oxygen combine together with tremendous force.

A very pleasant modification of this experiment can be

made if you have in your laboratory cylinders of compressed hydrogen and oxygen. (You will see that the oxygen-cylinder is painted black and the hydrogen one red, to prevent them from being mixed up. If this were not done and you accidentally used hydrogen in an experiment, when you meant to use oxygen, you might get a serious explosion.) Connect a rubber tube from the oxygen cylinder and one from the hydrogen cylinder to the two arms of a Y-tube. Then connect the Y-tube, by means of another piece of rubber tubing, to a clay pipe. Turn on the tap of the hydrogen cylinder a little, and, dipping the pipe into some soap solution, blow bubbles of the gas. When the bubble is big enough, detach it from the pipe by a gentle jerk, and you will see that it rises very rapidly through the air, just like a balloon filled with hydrogen would do. If you stand by with a lighted taper you may be able to get the flame into the bubble as it shoots up, but you will have to be quick and dexterous. After you are tired of this pastime, turn on the oxygen as well, very gently at first. The bubbles now will not rise so quickly, for they contain both oxygen and hydrogen, and oxygen is slightly *heavier* than air. When you get the flame into one of these bubbles, the gas no longer burns quietly, as it did when you were using hydrogen alone; it now explodes. What you must aim at is to adjust the proportion of oxygen to hydrogen so as to get the explosive mixture producing the loudest bang. When you have accomplished this, you will be able to have an enjoyable five minutes exploding the bubbles as they rise. They still go up fairly quickly, but they are now much more easy to catch.

What is formed when Hydrogen burns?—We know that when the electric current is passed through water, the water is split up into hydrogen and oxygen. Does it not seem likely that when hydrogen is burnt water is formed? When substances burn in the air, they combine with the oxygen in it; hence, if we burn hydrogen in air, we should

expect the hydrogen and oxygen to combine, and as we know that water is made of these two gases we should be surprised if water were not formed. We must, however, not trust to reasoning alone, but make an experiment to find out.

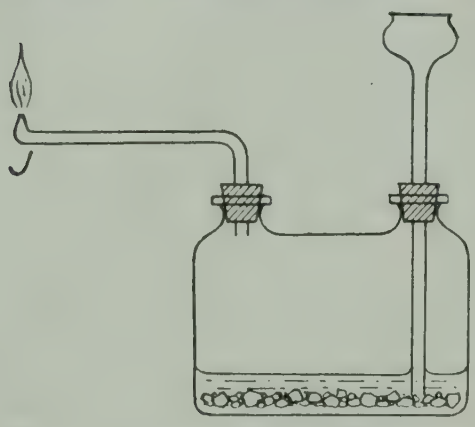


FIG. 31. APPARATUS FOR BURNING HYDROGEN IN AIR

Set up an apparatus like that shown in Fig. 31. In the two-necked bottle place some granulated zinc and through the funnel add dilute sulphuric acid. Hydrogen comes off at once, and after a time will have displaced all the air from the apparatus. It is clear that we must not light the hydrogen at the jet J until this stage has been reached, or the apparatus may explode. To make quite sure, we collect a test-tube full of the gas at the jet, and, removing it to a safe distance, we apply a lighted taper. If the gas which is coming off is still a mixture of air and hydrogen,

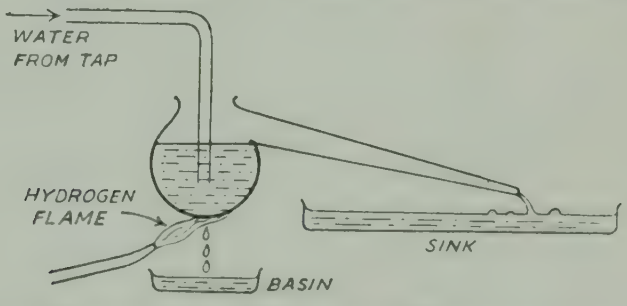


FIG. 32. FORMATION OF WATER BY BURNING HYDROGEN

it will explode with a shriek, but if it is pure hydrogen it will burn quietly. When this is so, we may safely light the jet. If we now allow this flame of burning hydrogen to touch the bottom of a glass vessel which is kept cold

by making a stream of cold water pass through it (Fig. 32), we find that the glass becomes dim, and that a liquid collects on it, finally dropping off, when sufficient has formed, into the basin placed below to receive it.

The liquid thus formed certainly looks like water, but it is not safe to trust to appearance only: we must make a closer examination. Let us taste it; it is tasteless, like water. If we boil some in a test-tube it is found to boil at 100° C., which is the boiling-point of water. Similarly, if we freeze it we get ice formed. Hence it must be water. We have thus not only split water up, or *analysed* it, into hydrogen and oxygen, but have also built it up, or *synthesised* it, from these two gases.

Natural Waters. — Although we call rain-water, sea-water, spring-water and river-water all by the single name "water," yet we all know that these different varieties of water are easily distinguishable from one another. However thirsty we were, for example, we should never think of drinking sea-water, for we know that it would make our thirst a thousand times worse. How is it that sea-water is different from rain-water, and what causes the difference? If we put a tablespoonful of sea-water into a clean evaporating-dish, and about the same quantity of rain-water into another dish, and then heat the basins until the water has evaporated, we find that there is practically no residue from the rain-water, whereas the sea-water leaves a good deal of white powder. If we taste this powder, we shall not be left in doubt as to what it is—it is *salt*. Sea-water differs from rain-water, then, in that it contains salt dissolved in it, whereas rain-water does not. Sea-water is therefore not *pure* water at all, but a *solution* of salt in water, and here we become acquainted with one of the chief properties of water, namely, its power of *dissolving* substances.

When we put a lump of sugar into a cup of tea, after a time the sugar disappears; it has, in fact, dissolved. It has not been destroyed, for we can taste it in the tea. Similarly,

if we put a spoonful of salt into a beaker of water and stir it up, the salt slowly dissolves and we are left with a clear liquid which is called a solution of salt. To get the salt back again all that we need to do is to evaporate the liquid, when the water is driven off in the form of steam and the salt is left. When we dissolve a solid in a liquid, the latter is called the *solvent*, the solid is called the *solute* and the product is called a *solution*. Water is an extremely good solvent, that is, it will dissolve a great many different substances. Hence "natural" water, or water which occurs in nature as opposed to the pure water we can obtain in the laboratory, always has more or less solid matter dissolved in it and is therefore not pure. The kind of impurity which the water has in it depends, of course, upon the kind of rock or soil over which the water has flowed. Let us trace the passage of some water from the sea back to the sea again. Sea-water, as we know, contains a good deal of salt and similar substances. When the sun shines upon the sea, some of the water near the surface is converted into water vapour, which is taken up by the air. The solids which were dissolved in the sea-water, however, are not converted into a gas and are therefore left behind. They do not separate out as a solid because the remaining sea-water is still sufficient to dissolve them.

The water vapour which rises into the air is thus *pure*, as it has left its dissolved substances behind. Now, after a time, the sun will have evaporated so much water that the air is nearly *saturated* with it, that is, it now holds so much that it can scarcely hold any more. Winds arise and blow this moisture-laden air over the land. Here it may become cooled. Cold air cannot hold so much water vapour as hot air; hence, if the moist air becomes cooled sufficiently, a time will come when the amount of moisture or water vapour in the air is above the saturation-point, and then the excess of moisture will condense to liquid water and a shower of *rain* occurs. If the air is cooled very much and

very quickly, the vapour may not condense to liquid water at all, but may become converted directly into solid water, or *ice*, which then settles down through the air in the form of snowflakes. Sometimes it happens, too, that as the rain falls through the air it meets with a current of much colder air on its way. If so, the raindrops may freeze as they descend, and we then get a *hail*-storm.

When the water reaches the ground it flows over and through the soil, and if there is anything in the latter which it can dissolve it does so, and therefore begins to be impure. From the surface of the soil the water finally finds its way into brooks and thence into rivers; the farther it flows the more impure it becomes as it has had more opportunity of dissolving substances. At last the river reaches the sea and the water has thus returned to the place whence it set out, but it has brought a good deal of dissolved matter with it. Hence we see that everything in the soil which will dissolve in water is gradually being transported to the sea, where it accumulates.

Hard and Soft Water.—Everybody knows the difference between hard water and soft water, and no one would choose hard water to wash in if he could get soft. Why is this? It is mainly because it is very difficult to get a lather with soap in hard water. When you try to wash in hard water, you notice that, instead of getting a lather, you get a large quantity of dirty bluish-white curds formed, and after a time the water becomes quite thick with them. If you continue to rub on the soap, you may at last produce a lather, but the process is very slow and you require a great deal of soap. With soft water, however, you get a lather at once. In order to explain these interesting facts, we must first learn something about soap and then try to find out what happens to the soap when it is rubbed up in hard water.

Soap.—Soap has been known for thousands of years. People in the ancient world used to make it in the following

way. First of all they burnt a lot of green plants and so obtained a greyish ash. They then stirred up the ash with water, so as to allow any soluble substances to dissolve. The insoluble residue was allowed to settle and the clear solution was evaporated in pots. After the water had been evaporated a white substance was left which they called pot-ash: a name which we still use, though nowadays we leave out the hyphen and say merely "potash." Moreover, we can now prepare this white solid in a more convenient way, but, bearing in mind the way in which it was first obtained, we still call it potash.

The ancients used to take a solution of potash and boil it up with mutton-fat. After a few hours they obtained a soapy liquid from which they were able to make soap separate out by adding salt. Even after so great a lapse of time soap is still prepared in the same kind of way. Chemists have, however, investigated the changes which go on in the process, and have discovered the composition of soap, mutton-fat and potash. They showed that mutton-fat is a compound of two things, namely glycerine and a white greasy solid which they call stearic acid. When the mutton-fat is heated with potash, the latter combines with the stearic acid and forms *stearate of potash*, or "potassium stearate," while the glycerine is set free and can be extracted and used for medicinal and other purposes. The potassium stearate is the substance which we call "soap":

Mutton-fat + potash = glycerine + soap
(glycerine + stearic acid) (stearate of potash)

Potassium stearate is the variety of soap which we call "soft soap," and which is usually sold in tins. The ordinary hard white soap is a very similar substance. It is made in exactly the same way, except that in place of potash we use a compound called *caustic soda*, a chemical which you will be certain to see in your science laboratories. It is made from common salt and closely resembles potash. Ordinary soap, then, instead of being stearate of potash, is *stearate*

of soda, or "sodium stearate." To make it, mutton-fat is boiled up with a solution of caustic soda for some hours. Afterwards the residual liquid is allowed to cool and then some salt is stirred in. Particles of soap then separate out —a change known as the "salting-out" of soap—and these particles can be strained or filtered off and squeezed together into the familiar tablets or bars. Fancy soaps are made by adding some colouring-matter and a little scent.

Action of Soap on Water.—When soap is rubbed up in distilled water or in soft water it dissolves and forms a solution with a "soapy" feel. This liquid readily foams and froths, forming a lather, and it has the power of dissolving grease and so loosening particles of dirt which may be held in the grease. Hence it is used for cleansing purposes. When, however, it is rubbed up in *hard* water, it refuses to lather and we get a heavy curdy precipitate formed. Chemists, of course, were very interested in this change and collected some of the curds so that they could find out what they were made of. They found that the curds consisted of stearic acid and lime; they were, in fact, "stearate of lime," or, to give them their proper chemical name, *calcium stearate*. It was clear, therefore, that the reason why hard water will not lather with soap is that the water contains something which destroys the soap and converts it into the curdy solid calcium stearate.

If we evaporate a little hard water in a clean basin, we shall find that a white powder is left. This is chalk or limestone, as we can easily ascertain by the following experiments. When we take a piece of limestone and pour some dilute hydrochloric acid upon it, the mixture fizzes, or effervesces, and a clear liquid is left. The gas which comes off will turn lime-water milky and is therefore carbon dioxide (p. 47). A drop of the clear liquid, if taken up on a loop of platinum wire and then introduced into the Bunsen flame, turns the latter a reddish-orange colour. Now, if we test the white powder left in the basin after the

evaporation of the hard water, we shall find that (*a*) it effervesces with dilute hydrochloric acid, giving off carbon dioxide, and (*b*) the clear liquid left from experiment (*a*) will turn the Bunsen flame a reddish-orange colour. We can therefore feel certain that the residue is limestone.

Hard water therefore contains limestone. So perhaps we could make some hard water by dissolving some limestone in distilled water. If you try this you will probably be surprised at the result, for you will find that *the limestone will not dissolve*! Here is an unexpected fact. The limestone left in the basin certainly came out of the water, but when we try to put it back again, or in other words to redissolve it, it refuses! How are we to explain this strange occurrence? Well, it is of no use merely to *think* about it; we must take some more hard water, evaporate it, and observe carefully to see if we missed anything the first time. Instead of heating the hard water in a basin, let us on this occasion heat it in a test-tube, so that we can keep it under observation better. Is there any change which we did not see before? When you try this, you will soon find that there *is* something which was overlooked before, viz. bubbles of a gas come off. Perhaps this is the clue to our difficulty. We must collect the gas and try to ascertain what it is. Fortunately it is a gas which we know already and one, too, which is easy to identify. If it is passed through lime-water the latter is turned milky, and so the gas is carbon dioxide.

Now, if limestone is contained in hard water and yet will not dissolve in distilled water, it seems likely that the cause of this difference is to be sought for in the carbon dioxide which is driven off from hard water on heating. Let us repeat our attempt to dissolve limestone in water, but this time we will bubble carbon dioxide through the water as well. We will take a small quantity of very finely powdered limestone, stir it up with distilled water in a large test-tube and then pass carbon dioxide through the

liquid. This time we are successful. After a while, all the limestone has dissolved and we are left with a clear liquid. If our arguments have been correct, this liquid should be —what? Why, nothing more or less than *hard water*! Whether this is so or not we can find out in a moment, by seeing whether it will lather with soap. We find that it will not, but that, on the contrary, it forms the characteristic curds of calcium stearate.

We have discovered, therefore, that (i) hard water will not lather with soap because it destroys the soap, forming curdy calcium stearate; (ii) hard water contains limestone; and (iii) the limestone is kept dissolved by carbon dioxide, which also is present in the water. Soft water, on the other hand, when evaporated leaves practically no residue, and hence, when soap is rubbed up with it, a lather is produced because there is nothing to decompose the soap.

How Hard Water is formed in Nature.—Having discovered what causes the hardness of water, we must next ask ourselves how hard water is formed in nature. Since many rocks and indeed many mountain-ranges are made of limestone (or of chalk, which is the same substance chemically), we do not have to seek far for one of the necessary constituents. When water vapour becomes cooled in the air and turns back to liquid water again, it falls to the ground as rain. At first it is very pure and perfectly soft; in fact, many people put barrels to collect the rain-water which falls on to the roof of their houses, so as to have soft water in which to wash. We have seen, however, that most water which is pumped up from the ground is distinctly hard in all places where limestone occurs in large quantities. The rain-water must therefore have dissolved some of this limestone as it trickled through or over the ground, and in order to do this it must have been able to dissolve some carbon dioxide first. Where did it get this carbon dioxide from?

When you were studying oxygen, you found that carbon dioxide is produced when carbon (charcoal, etc.) is burnt. Now coal consists mainly of carbon, and millions of tons of coal are burnt every day. Hence millions of tons of carbon dioxide are thrown into the air every day. As we have seen already, atmospheric carbon dioxide forms the chief food of green plants, so the amount of this gas in the air does not go on increasing all the while—it is eaten up by plants just about as quickly as it is produced. Nevertheless, there always is *some* carbon dioxide in ordinary air (about 3 litres in every 10,000), so that as the rain-drops fall they are able to dissolve a little of it. When they reach the soil they dissolve more carbon dioxide, for this gas is always present in soil, being formed by the breathing and decay of plants.

You see that the rain-water is now charged with carbon dioxide, so that if it at last flows over or through limestone (or chalk) rocks it is able to dissolve a little of the limestone, and so becomes hard.

How Hard Water is Softened.—If water is very hard it is unsuitable for domestic and commercial purposes. In the first place, it is very wasteful in washing and is also unpleasant. Secondly, when it is heated it deposits all its limestone, since the carbon dioxide is driven off and hence the water can no longer keep the limestone dissolved. This deposit of limestone causes "fur" in kettles and "rock" in boilers and hot-water pipes. A boiler which is regularly filled with hard water soon becomes lined with a thick coating of limestone which not only makes the capacity of the boiler less, but also renders it liable to crack. In hot-water pipes the deposit of limestone may in time completely block the pipe and so may easily cause an explosion. For these reasons, the water supplied to towns is usually softened at the waterworks.

We have already discovered that when hard water is boiled the carbon dioxide it contains is driven off and

the limestone therefore deposited. The water left will therefore be soft, so that here we have a method of softening hard water. It would be impossible to apply this method, however, to a reservoir. Blagdon Lake, which supplies the city of Bristol, holds 1,700,000,000 gallons or more: to boil this would require a volcano! Chemists therefore sought another way of softening hard water. If you think about it you will see that, if only a way could be found for removing the carbon dioxide from the water, the limestone would then be deposited and the water softened. Now, when you blow carbon dioxide into lime-water, the latter, you will remember, turns milky and the carbon dioxide is absorbed. What happens is that the carbon dioxide is seized by the lime in the water and the lime and carbon dioxide together form chalk, which comes down as a white solid, thus giving the milky appearance. Thinking over this fact, a chemist named Clark came to the conclusion that a good way to soften hard water would be to add to it just sufficient lime to use up all the carbon dioxide in the water. In this way all the lime which he added would be converted into chalk and so precipitated or deposited as a solid, while the hard water, having had its carbon dioxide removed, would now no longer be able to keep its limestone in solution, and this too would therefore be thrown out as a solid. He tried the experiment and found that it worked admirably.

By an analysis of the water he was able to calculate exactly how much lime he would have to add. When he added it, he obtained a white deposit, consisting of limestone and chalk, and the water left was found to be quite soft. Clark's method is now extensively used for softening large quantities of hard water. First of all, an analyst takes a specimen of the water and analyses it, to find out how much carbon dioxide there is in each gallon. Then the total volume of the water in the reservoir is measured, and the proper weight of lime is calculated. This weight

of lime is then stirred up in the water, the precipitate allowed to settle, and the water thus rendered soft.

In actual practice, it is found better not to make town water *quite* soft. This is because soft water is rather insipid to the taste, and because it dissolves lead to a certain extent. If soft water is passed through lead pipes a little of the lead is dissolved. When this water is drunk, the lead remains in the body, so that if a man were to go on drinking such water month after month sufficient lead would finally accumulate in him to give him severe lead-poisoning. Hard water, on the other hand, does not dissolve lead. Hence, when preparing water for a town supply, care is taken (*a*) to see that it is not perfectly soft, so as to prevent lead-poisoning, and (*b*) to make it fairly soft, so that it shall not deposit "rock" (limestone) in boilers, pipes, etc., and so that it shall be pleasanter and more economical for washing purposes.

Solutions.—In this chapter we have often talked about "dissolving" and "solution," and it was explained (p. 82) that a solution consists of two parts: (*a*) the liquid which does the dissolving, called the *solvent*, and (*b*) the substance which is dissolved, called the *solute*. Water is an extremely good solvent; in other words, it dissolves a great many different substances. Thus salt, sugar, soda, nitre, sal-ammoniac and blue vitriol (copper sulphate) all dissolve very easily in it. Mutton-fat, candle-wax, metals, glass and other things you can easily think of are, however, *insoluble* in water. On the other hand, candle-wax will readily dissolve in petrol, while salt will not. Petrol is therefore a solvent for candle-wax but not for salt, while water is a solvent for salt but not for candle-wax. Metals will dissolve in neither petrol nor water, but a great many of them will dissolve easily in mercury, forming solutions which are called amalgams.

If we take a definite volume of water—say 100 c.c.—we cannot dissolve in it an *unlimited* weight of salt or of

anything else. Let us take this volume of water in a beaker and add salt to it, a little at a time. At first the salt dissolves and we have a clear solution. Finally, however, we reach a point at which no more of the salt dissolves. If we continue to add it, it merely sinks to the bottom and remains there as a solid. *When a solution will dissolve no more of its solute it is said to be saturated;* weaker solutions, which have not yet reached this stage, are called *unsaturated.*

Further investigation would show us that 100 c.c. of hot water require more salt before the solution is saturated than do 100 c.c. of cold water. That is, salt is "more soluble" in hot water than in cold. When talking about the *solubility* of a substance in water, therefore, we have to *state the temperature* at which the solubility is measured. In order to get a standard for comparison of the solubilities of different substances, we define solubility in the following way.

Solubility. — *The solubility of a substance in a given solvent at a particular temperature is the maximum weight in grams of the substance which* 100 *grams of the solvent will dissolve at that particular temperature.*

The solubility of a substance in water is therefore the maximum number of grams of the substance which can be dissolved in 100 grams of pure water at the temperature concerned.

The solubility of salt does not increase very much with rise of temperature, i.e. salt is not much more soluble in hot water than in cold. The solubility of saltpetre (nitre, potassium nitrate), however, increases very rapidly with rise of temperature, as you will see by the figures given in the following table:

Solubility of Potassium Nitrate (Saltpetre) in Water.

Temperature in degrees (C.) .	0	10	20	30	40	50	60	70
Solubility	13	20	32	45	63	85	110	140

We see that, while 100 grams of ice-cold water will

dissolve only 13 grams of saltpetre, the same weight of water at 70° C. will dissolve no less than 140 grams!

In order to be able to see at a glance how the solubility of a substance varies with the temperature, it is convenient to make a curve on squared paper, plotting the solubility along the vertical axis and the temperatures along the horizontal axis. Such a curve, an example of which you will see in Fig. 33, is called a *solubility curve*.

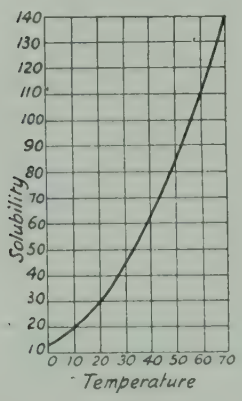


FIG. 33. SOLUBILITY CURVE OF POTASSIUM NITRATE (SALTPETRE)

The curve shown in the figure is the solubility curve of potassium nitrate. It shows us that the solubility of this substance increases rapidly and regularly with rise of temperature. It also enables us to estimate the solubility at any particular temperature by a mere inspection of the curve: thus at 38° we see that the solubility is 60.

Erosion.—The fact that water is such a good solvent is one of the reasons why it has played and still plays an important part in shaping the face of the earth as we know it. In the spring, a farmer often sprinkles a dressing of sodium nitrate (Chile saltpetre) over his wheatfields, to act as a manure and so to improve the crop. Although the wheat uses only a portion of this sodium nitrate, none is left in the soil after the following winter, and a fresh dressing has to be put on for the next crop. The explanation of this fact is very simple. Sodium nitrate is even more soluble in water than the similar compound potassium nitrate. The rain that falls on the soil therefore dissolves it, and the runnels and rillets, feeding the brooks and the rivers, soon carry it away to the sea.

Now, although few substances dissolve as readily in water as sodium nitrate does, yet practically everything *is* soluble in water, to a greater or a less extent. Moreover,

as we have seen, rain-water contains dissolved carbon dioxide, and this solution of carbon dioxide can dissolve limestone and chalk. The rain which falls on the earth year after year and century after century is therefore "eating away" or *eroding* the rocks and the soil. Slow as the process generally is, it finally produces great effects. A thousand —even a hundred thousand—years are nothing to Nature, and the slight erosions caused by single storms begin to tell when they are all added together.

It is not only rain-water which thus affects the surface of the earth. The sea performs its share, too. Ceaselessly dashing against the rocks on the coasts, it at last succeeds in cracking and splitting them. The huge boulders which are first formed get broken up still further by the relentless and never-ending force of the waves, and are converted into pebbles. At first the pebbles may have sharp edges, but by being continually ground together they get rounded off and smoothened. Even then, however, the sea is not satisfied. It crushes and rubs and grinds them, so that they become smaller and smaller, and at last they are turned into grains of sand or into finer particles of silt and mud.

In many parts of England this erosion of the sea-coasts by the ocean is a very serious matter. Towns that centuries ago were flourishing and teeming with people now lie far out under the waves, and the encroachment still continues. Fortunately, in other parts the sea is receding, and what was the coast in bygone years is now perhaps some miles inland. If, for example, you look at a map of the south-east coast of England as it was in the days of Julius Cæsar, you will find that the site of the present Dungeness is some miles out at sea!

In its solid form—ice—water has done much to alter the surface of the earth. Thousands—perhaps millions—of years ago, most of Europe was covered with huge glaciers. Even in England you can see rocks which have been

scratched deeply by the ice that passed over them in the Glacial Age.

Water-power.—When, a moment ago, we were talking about the force of the waves upon the sea-coast, you may have wondered whether all this power might not be harnessed and made to do useful work instead of merely destroying our island little by little. At the seaside, too, you have all watched the tide come in, and perhaps you have thought of the immense weight of water which is thus moved twice a day. On the Bristol Channel the tide may rise as much as forty feet! Think, again, of the tremendous weight of water which falls over Niagara or over the Zambesi Falls every hour. Cannot man make some use of this force?

This question was answered long ago by the man who invented the first water-wheel. If falling water is allowed to flow over a water-wheel, the latter revolves and can be made to work machinery. It can, for example, be made to drive millstones and thus to grind corn. Mills worked by water-power have been in use from very early days, and for long the water-wheel of the corn-mill was practically the only way in which water-power was employed. Nowadays, however, engineers harness a waterfall much more efficiently. They still make it drive a kind of water-wheel, but this improved water-wheel is made in turn to drive a dynamo (p. 157), or machine which produces electricity. Herein lies one of the reasons why water-power is being used more and more extensively every year, for electricity can be conveyed to any desired distance along wires or cables. In the days before the dynamo was invented, a waterfall was of no use to a town if the latter was several miles away, for the machinery to be worked had to be close to the fall. At the present time, however, the fall is made to work dynamos and the electricity so produced is sent along cables to towns perhaps many miles distant. This is what is done at Niagara. Here there is

a very large power-station, with tremendous dynamos worked by the "water-wheels," which are themselves made to revolve by the force of the falling water. The electricity made in this way is then distributed to neighbouring towns, so that a man miles away can warm himself at an electric fire, read by electric light or travel on an electric tram, and possibly never dream that these conveniences are due to the water at Niagara.

It is interesting to observe here how advances in one branch of science may help others. Until dynamos were invented, it was not possible to make a great deal of use of water-power. Conversely, the use of water-power has, in many places, made electricity extremely cheap and has thus led to a closer study of the properties of electricity and the invention of new electrical instruments. The use of water-power is of interest in another way. At the present time coal is expensive, and it is from coal that we obtain gas, so that this is expensive, too. Moreover, in the majority of towns, coal is used to produce electricity and to drive machinery of all kinds. In places which are far from a coal-field, the cost of carriage has to be added to the cost of the coal, so that in these districts heat, light and power may be very expensive indeed. If, however, there happen to be waterfalls in the neighbourhood, it may be possible to utilise them, and so to avoid the necessity for large quantities of coal. In Norway and Sweden, where waterfalls are numerous, each little town—nay, each hamlet—has its own electric power-station, worked by the local fall, and the inhabitants are therefore able to have good light in their houses, inexpensive heat in cold weather, and cheap power for their factories. The same is true of many districts in America, and there seems to be no doubt that in the future, when our supplies of coal gradually become exhausted, we shall have to rely more and more upon water-power.

CHAPTER V

EARTH

Earth is not a Simple Substance.—To go back once more to that greatest of all men of science, Aristotle, we remember that he believed all substances to be composed of four simple substances or "elements," fire, air, earth and water. Now, although Aristotle may well have believed that fire, air and water were simple substances, since very little was accurately known about them in his time, his powers of observation were as keen as those of any man who has ever lived. He could not, therefore, have believed that ordinary "earth" or soil was a simple substance, for it is obvious to even the most casual observer that in soil some particles are very different from others, and that the general character of the soil in one district may be entirely unlike that in another. What, then, did Aristotle mean by "earth"? It is difficult to say with confidence, but he probably believed that if any substance could be analysed, or split up, after all the "fire," "air" and "water" which it contained had been driven off, there would be left a solid, powdery residue. This residue he believed would be the same whatever substance was taken for analysis, and this is what he no doubt meant by the "earthy" part of bodies. His idea was, of course, only a guess, for in those days analysis, such as a chemist carries out to-day, was quite unknown. We have already seen the kind of evidence upon which he may have based his suggestion (p. 10), and can readily admit that, from the facts he knew, his guess was a very reasonable one.

Boyle's Idea of an Element.—For two thousand years

Aristotle's Four Elements held their sway over the minds of men of science. Then, in Charles II.'s reign, the great Irishman Robert Boyle came to the conclusion that Aristotle's views were not only incorrect, but also harmful to the progress of science. He said that chemists should abandon the old theory of four elements and adopt a different idea of the nature of an "element." In his book, the *Sceptical Chymist*, published in 1661, he writes:

> I mean by *elements* . . . certain primitive and simple or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the ingredients of which [all other substances] are immediately compounded, and into which they are ultimately resolved.

Translating this passage into modern and more simple English, we understand that Boyle meant this: that, to a chemist, an "element" is *any* substance which he has not yet split up into two or more substances; and that of these elements all other substances are composed and into them all other substances may be split up. How does Boyle's definition of "element" differ from that of Aristotle? In the first place, instead of limiting the number of elements to four, Boyle says that he regards *any and all* substances, however numerous they may be, as elements—until someone succeeds in splitting them up. Secondly, he says that fire, air, earth and water must pass the same test as the rest; if anyone can show that any one of these so-called "elements" can be split up, or analysed, into two or more simpler substances, then it must no longer be called an element by chemists.

Importance of Boyle's Suggestion.—This suggestion of Boyle's gave science very great assistance, for, when it was generally adopted—an event which did not occur immediately—it gave chemists a very definite principle on which to work. After they had had time to think it over, they agreed that it was useless to regard certain things which they *could* split up as elements and other

substances which they could *not* split up as compounds. It was, in fact, as everyone finally agreed, not merely useless but very confusing. Later on, in the eighteenth century, Aristotle's idea was completely abandoned, and chemists succeeded in splitting up water into hydrogen and oxygen (p. 74), and showed, too, that air is not a simple substance, for it contains at least two gases, namely oxygen and nitrogen.

Elements, Mixtures and Compounds.—Nowadays, chemists —like Cæsar with Gaul—regard all substances as divisible into three classes, which they call in their language *elements*, *mixtures* and *compounds*. We have already seen what they mean by an element. Now let us try to understand what they mean by mixtures and compounds. If we take some powdered iron and stir it up with some powdered sulphur, we shall have a *mixture* of these two things. Have the iron and the sulphur been changed in any way by mixing them together? To answer this question we must know something about the properties of the two elements, and then we must make experiments to see if the iron and the sulphur, when mixed together, will each show the same properties as when they are separate from one another.

One of the most characteristic properties of iron is that it is attracted by a magnet: so here we have one test to apply. Sulphur, on the other hand, is not attracted; it will, however, dissolve in a colourless and very volatile and inflammable liquid called *carbon disulphide*—a liquid which, as usually met with, has a very nasty smell, but when quite pure is not nearly so objectionable. Carbon disulphide, although it dissolves sulphur, will not dissolve iron. We can, again, use hydrochloric acid in our investigation, for this acid has no action upon sulphur, but when poured upon iron begins to *effervesce*, or to give off a gas. Examination of this gas shows it to be hydrogen: it is a colourless gas, very light, and burns with a bluish non-luminous (i.e. giving out no light) flame. The iron itself

disappears, having dissolved in the acid. These facts will be quite enough for our purpose.

Properties of a Mixture of Iron and Sulphur.—Suppose we take our mixture of iron and sulphur and hold a magnet just above it. If the iron is still there with its properties unchanged, it ought to leave the mixture and cling to the magnet. Try this for yourselves, and you will see that that is exactly what does happen. Take some more of the mixture, put it into a test-tube and add a little carbon disulphide. The sulphur dissolves more easily in warm carbon disulphide than in cold, but carbon disulphide is so inflammable that it is not safe to hold the tube over a flame; instead, it can be placed in some hot water. After a minute or two filter the hot liquid and see what is left upon the filter-paper. You will not be in doubt very long: it is *iron*, and there are no particles of sulphur now mixed with it. If you let the clear liquid which has run through the filter-paper evaporate, by putting it in a basin in a good draught, you will see that yellow crystals of sulphur are left.

Lastly, put a further portion of the mixture into another test-tube and pour on to it a little hydrochloric acid. You will see that a vigorous effervescence takes place and that a gas—which can easily be recognised as hydrogen—comes off. When the action is over, you will be able to see the sulphur particles floating about in the clear liquid that is left.

What do all these observations teach us? Well, they tell us just what we wanted to know, namely, that when iron and sulphur are mixed together, they each keep all the properties which they had when they were by themselves: the iron is still magnetic; it will still dissolve in hydrochloric acid, hydrogen being given off during the action; and it is still insoluble in carbon disulphide. The sulphur, again, is still soluble in carbon disulphide but insoluble in hydrochloric acid, and is still unaffected by a magnet.

This, indeed, is what we should expect and, when we examine the mixture by means of a lens, we can actually see the iron particles and sulphur particles lying side by side.

Effect of Heat upon a Mixture of Iron and Sulphur.—If we take a mixture of iron and sulphur and heat it in a test-tube, we are thrilled by the result. For, after a time, the mixture begins to get hot at a far greater rate than can be due to the heat of the flame we are using, and when the action has once begun we can indeed take the tube out of the flame altogether without stopping it. The mass inside the tube finally becomes almost white hot. After a time it begins to cool down, and when it is cold we can get at it by the simple expedient of breaking the tube—if it is not broken already!

What sort of a substance is this residue? Let us apply to it the tests we have already tried with iron and with sulphur, and see what happens. First, we find that it is not attracted by a magnet, so that it differs from iron in this respect. Secondly, if we crush it up and warm it with carbon disulphide, we find on filtering the liquid that the *filtrate*, or liquid which runs through the filter-paper, leaves no sulphur behind when it is evaporated. Thus, although the iron and sulphur are both contained in the new substance, the iron has lost its magnetic property and the sulphur can no longer be dissolved out in carbon disulphide. Let us next try the action of hydrochloric acid upon it. We notice that there is a brisk effervescence, just as there was when we added the acid to iron itself, or to the mixture of iron and sulphur. But we have only to *smell* the gas to realise that this time it is certainly not hydrogen: it has a powerful and very objectionable smell of bad eggs, and is the gas which chemists call *sulphuretted hydrogen*. Like hydrogen, it will burn, but when it does so it produces *two* things, viz. water, and the same gas which is formed when sulphur burns in oxygen, namely sulphur

dioxide. Hence it is reasonable to suppose that it consists of hydrogen and sulphur (*why?*).

These experiments have shown us that, when iron and sulphur are merely mixed together, each retains its own properties; but that when this mixture is heated an entirely new substance is formed. This new substance is known as *iron sulphide*. It contains both iron and sulphur, but they are now firmly joined to one another and cannot be separated by means of a magnet or carbon disulphide. We say, in fact, that in iron sulphide the iron and sulphur have *combined* together, and that iron sulphide is a *compound* of these two elements.

Further experiments have shown chemists that, when iron and sulphur combine together, they do so in perfectly definite proportions by weight. One gram of sulphur will combine with exactly $1\frac{3}{4}$ grams of iron—no more and no less. If we use a mixture which contains a higher proportion of iron than this, some of the iron will be left over. If, on the other hand, we use more than 1 gram of sulphur for every $1\frac{3}{4}$ grams of iron, some of the sulphur will be left over. The same kind of thing is true of all chemical compounds. Water, for example, always contains one-ninth of its weight of hydrogen and eight-ninths oxygen. Thousands of specimens of water have been analysed and this proportion has been found to hold good in all of them. About half a million chemical substances have been investigated and carefully analysed, and it is found that all samples of any one compound have exactly the same composition. This fact is conveniently expressed in the following statement:

All specimens of the same compound consist of the same elements combined together in a fixed proportion by weight.

The whole of chemistry rests upon this important fact.

You will now be able to understand the chief differences between mixtures and compounds, which can be summarised as follows:

(i) *The composition of a mixture may be made just what we like, but the composition of all specimens of the same compound is always the same.* If, for example, we mix sugar and sand, we can put as much or as little sugar as we like in the mixture. Similarly, if we mix iron and sulphur, we can do so in what proportion we please; but if we make the iron and the sulphur *combine* to form iron sulphide, we shall find that the compound always consists of iron and sulphur in the proportion of $1\frac{3}{4}$ (iron) to 1 (sulphur) by weight. This proportion it is quite beyond the power of any chemist to alter.

(ii) *Each constituent of a mixture retains its own properties, but the properties of a compound are different from those of its constituents.* Thus, sand is a hard and gritty substance which will not dissolve in water, while sugar is sweet and easily dissolves. If we taste a mixture of sugar and sand we can detect both the hard and gritty sand and the sweet sugar, while if we stir up some of the mixture in water the sugar dissolves and the sand does not. Each constituent of the mixture, in fact, keeps the properties it had before it was mixed with the other. When, however, we explode a mixture of hydrogen and oxygen in the proportion of 1 gram of hydrogen to 8 grams of oxygen, we get a new substance altogether, and we find that the properties of water are very different from those of hydrogen and from those of oxygen.

(iii) *When compounds are formed from their constituent elements, heat is generally given out.* When we *mixed* iron and sulphur, nothing happened; but when we caused them to *combine* the mass became incandescent. Similarly, if we merely *mix* hydrogen and oxygen, no heat is given out; but if we pass a spark through the mixture the two gases *combine* with great violence, and much heat is evolved. Ordinary coal-gas contains about 50 per cent. of hydrogen. When we burn it, the hydrogen combines with the oxygen of the air and we use the heat so formed for cooking our food, for warming our rooms, for driving machines and for

many other purposes. Indeed, if we examine the sources of the heat we employ in our daily life, we find that most of it is obtained during the formation of chemical compounds. Thus coal, which consists chiefly of carbon, is burnt in air. In this process it forms carbon dioxide, and heat is liberated. Wood, gas and oil contain both carbon and hydrogen, and when they are burnt carbon dioxide and water are found, together with a great quantity of heat.

Analysis. — Since Aristotle's "element" earth is no element at all, but a mixture of various elements and compounds, it becomes necessary to devise methods of finding out what these different constituents of the earth's crust are, and of separating them from one another. Men of science have devoted much labour to this problem of *analysis*, or "splitting-up," and although we cannot here go into the question deeply, perhaps you would be interested to know at least one or two of the different methods employed.

One very interesting way depends upon the fact that certain elements, and compounds which contain these elements, will impart definite colours to a non-luminous gas-flame, such as that which is given by a Bunsen burner or a gas-ring. Some of these colours you can easily obtain for yourselves, and you can then feel that you are actually carrying out one of the experiments that analysts frequently adopt. If you take a piece of platinum wire, mounted in a glass rod (Fig. 34A), and bend the end round into a loop, you will have a convenient instrument with which to introduce your substance into the flame. If you cannot get a platinum wire (platinum is far more precious than gold!), you can use one of the fireproof rods on which upright incandescent gas-mantles rest; it will do nearly as well.

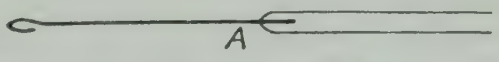


FIG. 34A. FLAME TESTS

In a watch-glass place a few drops of concentrated hydrochloric acid. Dip your platinum loop into this and

then heat the loop in the flame. Repeat until the flame is no longer coloured; the wire will now be clean. Dip the wire into the acid again and then take up in the loop a little common salt and heat it in the flame. Is the flame coloured?

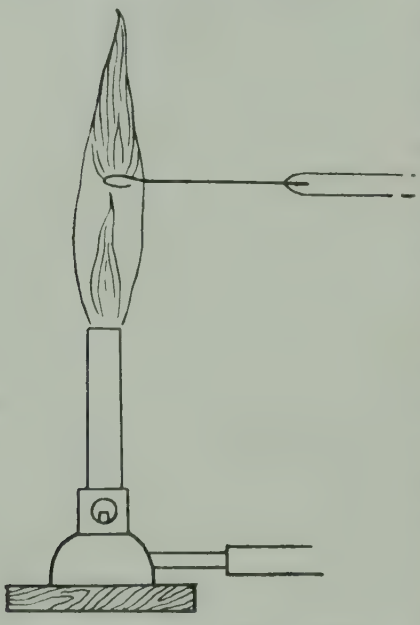


FIG. 34B. FLAME TESTS

Clean your wire as before, and then heat some Chile saltpetre (sodium nitrate). Note the colour of the flame. Repeat with (*a*) Glauber's salt and (*b*) washing-soda. You will find that each of these substances colours the flame a brilliant golden-yellow. Now salt, Chile saltpetre, Glauber's salt and washing-soda *all* contain the element sodium, and it has been found that every substance in which sodium is present (and no others) will give a flame this golden-yellow hue. Here, therefore, we have a *test* for sodium. Suppose the doctor gives you a powder to take, and that you would like to know something about its composition. If you moisten a platinum wire in hydrochloric acid, dip it into a little of the powder and then heat it in the flame, you can easily tell whether it contains sodium or not. If it turns the flame golden-yellow it does; otherwise it does not.

When you have finished with the sodium compounds, try compounds of (*a*) copper, (*b*) potassium, (*c*) calcium, (*d*) strontium, (*e*) barium. You will find that they give the following characteristic colours:

copper . . .	bluish-green
potassium . . .	lilac
calcium . . .	orange-red
strontium . . .	crimson
barium . . .	apple-green

Afterwards, ask your science teacher to give you unknown substances to analyse in this way: you will find it a very interesting task. You should also try the tests with any minerals you may find, and with Bordeaux mixture (used to spray potatoes), nitre and lime.

Another test is easy to carry out. It serves to detect *carbonates* or substances like limestone and washing-soda. All carbonates effervesce and give off carbon dioxide when they are treated with dilute hydrochloric acid, or indeed any dilute acid. Put some lumps of marble or limestone into a test-tube, and add a little dilute hydrochloric acid. Fit the test-tube immediately with a cork carrying a delivery tube, the end of which dips into a tube containing lime-water (Fig. 35).

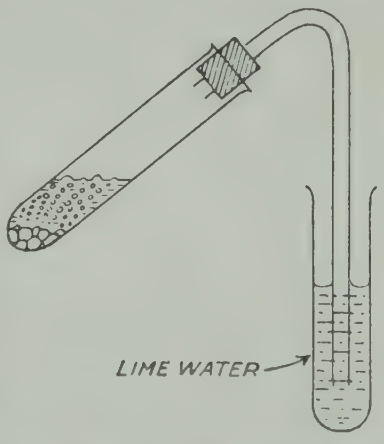


FIG. 35. TEST FOR CARBONATES

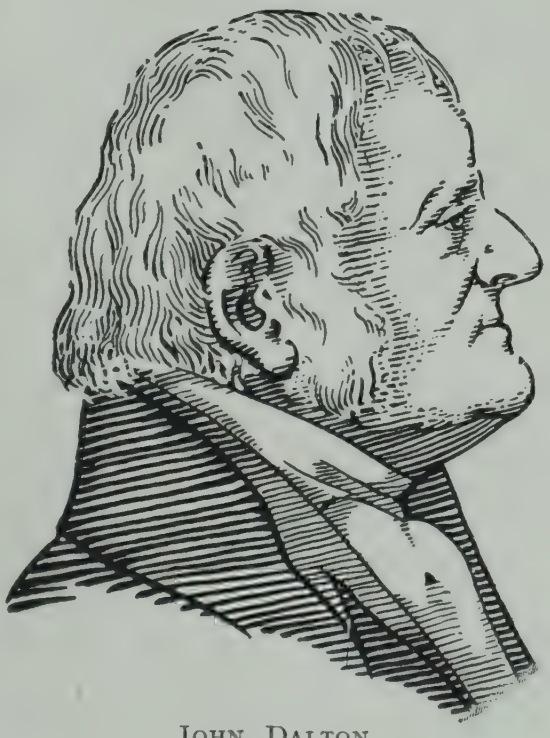
You will see that the lime-water is turned milky by the carbon dioxide which comes off. Repeat the experiment, using washing-soda instead of limestone. Is washing-soda a carbonate? Use also chalk and baking-powder; then see if you can detect a carbonate in garden or field soil.

Finally, as a third example of an analytical method, you should carry out the borax bead test. When borax is heated in a loop of platinum wire it first of all froths up, and then melts to a clear liquid. If it is now allowed to cool, the liquid sets to a hard glassy solid which we call "the borax bead." It is found that the compounds of certain elements have the power of colouring the bead if they are dissolved in it while it is still liquid. Take a platinum wire and make a loop at the end. Heat the loop in the Bunsen flame and then plunge it, while still hot, into some powdered

borax. Some of the borax will stick to the loop, which should now be heated in the flame again until the borax has changed to the clear glassy liquid. Now lightly dip the hot bead into some powdered cobalt chloride, thus taking up a tiny portion of the latter (be careful not to take more than a *very* small amount). Heat the bead in the flame again for two or three minutes and then allow it to cool. You will find that the borax bead is now of a beautiful deep blue colour. This colour is imparted to the bead by *any* compound of cobalt, and so the formation of a blue borax bead is used as a *test for cobalt.* You should make borax beads with compounds of the following elements as well, and make notes of the colours produced: copper; manganese; iron; chromium; nickel.

Atoms.—The kind of analysis of which we have just been talking is a *chemical* one; its object to analyse substances in the sense of finding out what elements they contain. Suppose we try to analyse an element! What will happen? Well, since an element is composed of one kind of matter only, it is clear that we shall not be able to split it up into two or more different substances. Suppose, however, instead of carrying out a *chemical* analysis upon it, we analyse it *mechanically*, i.e. we will first cut it up into small pieces. If we now take one of these small pieces and cut it up into still smaller pieces, and continue this process as long as we can, we find that we still have the element with which we started. But we ask ourselves: Suppose that we had sight keen enough and instruments sharp enough for the purpose, could we go on cutting up these tiny particles indefinitely, or should we at last reach particles which we could no longer divide? This is a question which men of science asked for two thousand years. Some of them believed that we should never get down to indivisible particles, while others maintained just the opposite. There were many wearisome arguments on both sides, but no one could think of any way of settling the question

experimentally. At last, at the beginning of the nineteenth century, a Manchester schoolmaster named John Dalton (1766–1844) thought of some methods of tackling the problem experimentally. He argued that if these extremely minute particles, which—using the old Greek word—he called *atoms*, really existed, then certain results ought to follow which could be tested in the laboratory. This is not the place to talk about the details of Dalton's scheme; it must be sufficient to say that his ingenuity first rendered it possible for scientists to get satisfactory evidence as to whether matter is composed of atoms or not. When the experiments were carried out, it was found that they all gave results which agreed with the idea that matter *is* composed of atoms. They did not actually prove it, but they rendered it very probable. At last, after a hundred years, Sir J. J. Thomson and other men of science were able to show that Dalton was right: that atoms certainly do exist; and that all substances are composed of atoms.



JOHN DALTON

Let us first try to picture to ourselves the actual size of an atom of mercury. It is a very difficult task, for even the tiniest drop of mercury which you can see contains millions and millions of atoms! Indeed, if you took a drop

of mercury and magnified it and magnified it till it reached the size of the whole earth, the atoms in it would then appear to be about as big as golf-balls! To take another example: suppose you had a glass globe about the size of an electric-light globe, and you pumped all the air out of it with an efficient air-pump, so that it was perfectly empty. If you then made a tiny hole in the glass, so that atoms could get in at the modest rate of 10,000,000 a second, how long do you think they would take to fill the globe? You may imagine that, since 10,000,000 is a very large number, a few seconds would be quite enough; but you would be far from the truth. As a matter of actual fact the time would be, not a few seconds, but 100,000 years!

Scientists have found that there are as many different kinds of atoms as there are elements. In other words, each element consists of its own peculiar variety of atoms, all the atoms of a particular element being alike, and different from those of all other elements. Thus an atom of gold is exactly like any other atom of gold, but different from an atom of silver or mercury or hydrogen or oxygen. The lightest of all atoms is that of hydrogen, while the heaviest is that of a metal known as uranium; the atom of uranium weighs 238·5 times as much as a hydrogen atom. Occasionally the atoms of elements go about by themselves, as in the "rare gases," such as helium. In other elements, however, it is found that two or more atoms always join up together to form groups of atoms or *molecules* ("little masses"); thus, if by some magic means you were able to see the molecules of oxygen in a jar of this gas, you would see a vast number of tiny groups, each consisting of a pair of oxygen atoms joined together.

Molecules of Compounds. — Since a compound must consist of at least two elements, it follows that the tiniest particle of a compound must contain *at least two* atoms, viz. one atom of each of the elements of which it is composed. Thus we cannot talk about an "atom" of a

compound: the smallest particle of a compound is a molecule. The simplest sort of compound molecule consists of one atom of one element combined with one atom of another element. Common salt, or, to give it its chemical name, sodium chloride, has molecules of this kind. Each of them consists of one atom of a metal named *sodium* and one atom of a greenish-yellow poisonous gas called *chlorine*. It may seem strange to think that the harmless salt of our table consists of such unexpected substances, but, from your work on iron and sulphur, you will remember that the properties of a compound need not be, and generally are

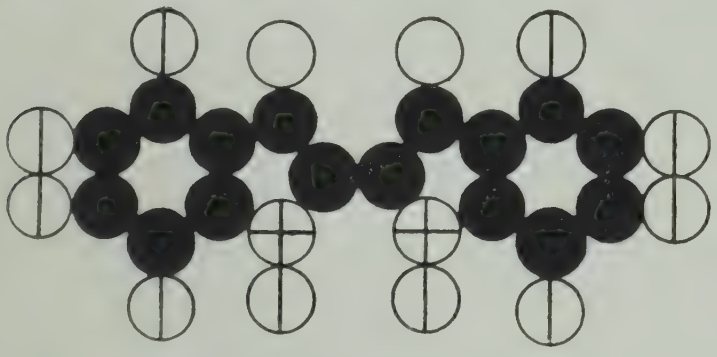


FIG. 36. THE MOLECULE OF INDIGO

not, anything like those of its constituent elements. In this particular case, sodium and chlorine are the constituents of the compound. Now sodium is a soft white metal which can be moulded between the fingers. If thrown upon water it melts and runs about on the surface, at the same time decomposing the water, setting free hydrogen. Chlorine is one of the poison-gases which were used in the European War. Yet common salt, which contains them both, is a white solid, soluble in water and quite indispensable to our daily life and health!

The number of atoms in the molecules of other compounds is sometimes very large. For example, the molecule of alcohol contains 9 atoms, that of cane-sugar 45; of alum 96; and of starch probably several thousand. In the

case of a great many compounds, chemists have not only been able to find how many atoms there are in the molecule, but also the actual way in which these atoms are arranged. Thus, in the molecule of the blue dye indigo, which contains 16 atoms of carbon, 10 of hydrogen, 2 of oxygen and 2 of nitrogen, it has been shown that the atoms are arranged as shown in Fig. 36.

In this figure, ● indicates an atom of carbon, ⓘ one of hydrogen, ○ one of oxygen, and ⊕ one of nitrogen. Later on in your science course you will find that the problem of discovering the arrangement of the atoms in the molecules of compounds is one of the most fascinating tasks imaginable.

Electrons and Protons.—Perhaps one of the most remarkable features about the discovery, in the early years of this century, that atoms really do exist, was the further and quite unexpected discovery that they are themselves complex structures. We have seen that the word "atom" comes from the Greek. It means *uncuttable* or indivisible. We have seen also that the atoms of elements are the exceedingly minute particles of which these elements consist. Now, although atoms are "indivisible" in one sense, since in all ordinary chemical processes they are unchanged, physicists have shown us that the atom of an element is not a simple body, but is composed of still tinier particles! Thus, an atom of oxygen is the smallest particle of oxygen which can exist, and if it is split up into the even tinier particles of which it is composed, these particles are no longer oxygen. What, then, are they? In the answer to this question we have one of the strangest and most interesting facts that man has ever discovered about the world in which we live. The tiny particles which compose an atom of oxygen are particles of *electricity*! Even more remarkable is the fact that the atoms of *all* elements are composed of particles of electricity. These particles are of two kinds: they are known respectively as *electrons* and *protons*. In Chapter VI.

you will read a little more about electricity, and you will find that electricity is itself of two sorts: *positive electricity* and *negative electricity*. Protons are particles of positive electricity and electrons are particles of negative electricity. In recent years, it has been found that each and every atom consists of one or more protons and one or more electrons. The proton is exceedingly small compared with an electron, but is nevertheless much heavier; in fact, a proton weighs about 1800 times as much as an electron, or about as much as a hydrogen atom. Since a hydrogen atom weighs about 0·000000000000000000000014 gram, you can see how inconceivably small the weight of an electron is!

All atoms, then, are composed of electrons and protons. The simplest atom is that of hydrogen, which consists of one proton and one electron. It is thought that the electron is continually revolving around the proton, so that we could represent a hydrogen atom by the following figure:

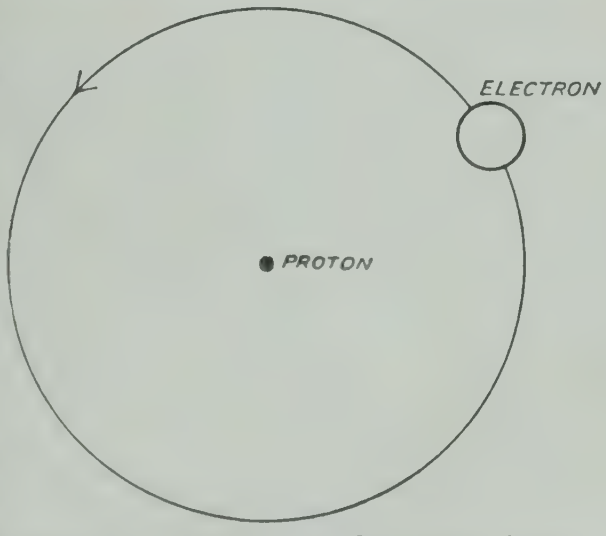


FIG. 37. STRUCTURE OF HYDROGEN ATOM

Other atoms have a more complicated structure, but in each of them there seem to be electrons revolving around a central positively-charged nucleus. An atom, then, instead of being a simple impenetrable sphere, such as it was supposed to be in days gone by, is really a kind of minute solar system, with a positively-charged nucleus as sun and electrons as planets. And just as the distance

between the sun and any one of its planets is far greater than the diameter of either, so is the distance between the electrons and the central nucleus enormously greater than the diameter of either an electron or a proton; in fact, the two ratios are of about the same order of magnitude.

One fascinating conclusion we can draw from the fact that *all* elements (and therefore, of course, all compounds) are made up of the same constituents, viz. protons and electrons, is that there is no reason why we should not be able to change one element into another. For example, gold consists of protons and electrons, and so does lead. Is there any reason why we should not be able to make gold out of lead? None whatever, except that so far we do not know what methods to employ. We know, in short, that it could be done, but we do not know yet how to do it. Now this *transmutation* of one element into another, and especially of lead or mercury into the precious metal gold, was the problem which engaged the attention of chemists for hundreds of years—from the fourth century to the end of the seventeenth. Many of them thought that they had accomplished it, but it has always, of late, been the custom to suppose that they either deceived themselves or were trying to deceive others. In view of our modern knowledge of the structure of matter, however, it seems just possible that by some lucky accident someone may have hit upon a method of transmutation. In any case, it is very interesting to remember that, in the most circumstantial accounts of transmutation which have come down to us, it is always *mercury* which is said to have been changed into gold; now, early in 1925, two Japanese chemists announced that they had been able to change mercury into gold, and in 1924 the same announcement was made by Dr. Miethe of Germany. It is too early to say yet whether these claims will prove to be justified, but Sir Ernest Rutherford of Cambridge University has undoubtedly been able to convert nitrogen into hydrogen and helium.

Radium. — Although chemists and physicists find it extremely difficult to split up atoms into the protons and electrons of which they consist, there is a certain metal the atoms of which are splitting up all the time of their own accord. This metal is *radium*. It was discovered, in a mineral called *pitchblende*, by Professor and Madame Curie of Paris, about the end of the nineteenth century. Radium atoms appear to be unstable, and in a piece of the metal or of any of its compounds a certain number of them explode each second. When a radium atom explodes it shoots out a *helium* atom with tremendous speed (several thousand miles a second), and a gas which Sir William Ramsay called *niton*. Niton itself is unstable and breaks down into other products, the final one being lead.

MADAME CURIE

Owing to the explosion of its atoms, radium shows very remarkable properties. Thus it shines in the dark and is always warmer than its surroundings; in other words, it is giving out *energy*. If other atoms could be split up, they also would yield energy, and scientists have calculated that, if the atoms in a lump of sugar could be split up into protons and electrons, enough energy would be liberated to drive the *Mauretania* from Liverpool to New York! No doubt in the future this problem will be solved, and then we shall no longer have to wonder what will happen when all the coal and all the oil in the world are exhausted.

How Old is the Earth?—The study of radium has thrown some light on the question of the age of the earth. The remarkable property of spontaneous explosion possessed by radium atoms led chemists to examine other elements more closely to see if further examples of this kind of change could be detected. The search was rewarded. It has been found that two metals called *thorium* and *uranium* are also slowly splitting up, and that the final product in each case is lead. The rate at which thorium and uranium are changing into lead has been calculated, and the results so obtained have been applied as follows. Certain minerals are known which contain a high proportion of uranium and a small proportion of lead. It is argued that probably the lead in the mineral has been formed by the splitting-up of some of the uranium. By analysing the mineral and finding the ratio of the weight of lead to the weight of uranium, scientists can calculate, approximately, the length of time which must have elapsed while the lead was being formed. Surprising figures have been obtained. If the argument and the data are correct, we learn that the earth is probably no less than 1,400,000,000 years old!

The age of the earth's crust has been determined in other ways. One of the simplest is based upon a calculation of the weight of salt in the sea. Salt, being soluble in water, is continually being washed out of the earth's crust by rain, and is then carried down to the sea by rivers. It is a comparatively simple task to estimate how much salt is thus swept into the sea every year, and also to find the total weight of salt in all the sea-water in the world. Then, by dividing this total weight by the weight carried down each year, we get the number of years which must have passed since the sea first began to get salt, i.e. the number of years since the earth's crust was formed. Calculations of this kind show us that the earth's crust is about 175,000,000 years old.

Composition of the Earth's Crust.—Chemical analysis

of the air, the sea and the crust of the earth has proved that the most abundant element is oxygen, which forms about 50 per cent., or one-half, of the whole. The chief remaining constituents (in parts per cent.) are shown in the following table:

silicon	26·03	potassium	2·33
aluminium	7·28	magnesium	2·11
iron	4·12	hydrogen	0·41
calcium	3·18	chlorine	0·20
sodium	2·33	carbon	0·19

About ninety-two elements are known altogether, so that, subtracting the percentages of the eleven elements given above, the remaining eighty-one elements account for only 3 per cent., by weight, of the whole.

Metals and Non-metals.—If you were given a piece of chalk, a penny, a pen-nib and a lump of sugar, you would have no difficulty in deciding which of these objects were metallic and which were not. Have you thought of the properties by which you make your decision? Possibly you have not, so let us consider the matter shortly. You will say, first of all, that a metal is "heavy," whereas non-metallic substances are usually not so heavy. Gold, silver, copper, iron, lead and zinc are all very heavy and are all *metals*, whereas hydrogen, oxygen, carbon and sulphur are non-metallic elements and are all "light." Secondly, you may say that metals can generally be given a high polish, whereas non-metallic things cannot. In both cases you would be right, to a certain extent, and these two characteristics are generally sufficient, in every-day life, to enable you to distinguish between objects which are metallic and those which are not.

In science, however, it is necessary to be a little more definite. It has just been mentioned that some ninety-two elements are known. These elements are divided by chemists into two classes: the *metals* and the *non-metals*. Examples of the two classes have already been given. When we come

to examine other elements, however, we find that it is not easy to say in which class they are to be put, so perhaps it will be best to see if we can think of any more properties of metals; we shall then be in a better position to consider doubtful cases. If you reflect on the common knowledge of metals which you have gained from daily life, you will agree that they generally have the following properties:

Properties of Metals.

1. They usually have a peculiar shininess or "lustre," which is indeed so characteristic that we describe it simply as a "metallic lustre."
2. They can usually be highly polished (e.g. steel, silver, copper, nickel).
3. They are generally "heavy," i.e. a small volume of a metal has a large weight.
4. At ordinary temperatures they are all solids, with the exception of mercury.
5. Heat can pass along them very readily. Thus the silver handle of a silver teapot soon becomes too hot to hold.
6. Electricity can pass along them very easily. Thus copper wires are used for electric cables.
7. As a rule they have to be heated to a fairly high temperature before they melt.
8. They can be drawn out into wire (i.e. they are *ductile*). They can also be hammered out into thin sheets (i.e. they are *malleable*).

Non-metallic elements, on the other hand, generally have the following properties:

Properties of Non-metals.

1. They do not have a metallic lustre.
2. They cannot be highly polished.
3. They are usually "light," i.e. a large volume of a non-metal generally weighs comparatively little.

4. At ordinary temperatures many of them are gases, e.g. hydrogen, oxygen, nitrogen and chlorine.
5. They do not allow electricity or heat to pass along them readily. For example, a *wooden* handle on a silver teapot becomes only slightly warm.
6. They generally melt at fairly low temperatures.
7. They are not malleable or ductile.

Chemically there is a further distinction between metals and non-metals. When an element is burnt in oxygen, it forms, as we have already seen (p. 44), the *oxide* of the element. Now the oxides of non-metals, when dissolved in water, form solutions which will turn blue litmus red, i.e. solutions which are *acid*. Metallic oxides, on the other hand, do not form acids in this way. They are generally *insoluble* in water; but if they do dissolve, they form solutions which will turn *red litmus blue*, i.e. *alkaline* solutions.

If an element shows all the properties which have been mentioned above as characteristic of metals, we can describe it with confidence as a metal. Similarly, any element which shows all the properties of non-metals is certainly a non-metal. Sometimes, however, we meet with an element which has some of the properties of metals and some of the properties of non-metals. Examples of such elements are antimony—a substance very popular for making trinket-boxes, etc.—and arsenic. These are sometimes known as *metalloids* ("like metals"), to indicate that while they more or less resemble metals they cannot definitely be regarded as true metals.

Metallurgy.—The art of extracting metals from the earth is an extremely ancient one. Earlier in the book some information about the use of metals in ancient times was given, but we must now deal with the subject in more detail. Cæsar tells us that in his time (54 B.C.) iron was produced in Britain, but in such small quantities that it was quite a rarity. It was, in fact, a precious metal to the

ancient Britons, who used iron bars as money. When the Romans settled in Britain, however, they soon began to work iron upon a large scale, and it is related that the armourer of the Twentieth Legion, Julius Vitalis, was given a public funeral at Bath by the "Blacksmiths' Union" there! In later years the industry grew still more: in the reign of Richard Cœur de Lion, for example, the Forest of Dean ironworkers made 50,000 shoes for the horses which the king took with him on his crusade.

Lead and silver also were mined in Britain in Roman days, and the remains of the Roman lead-works are still to be seen on the Mendips in Somerset. Here too was found a large block of lead stamped with the title of the Emperor Claudius (A.D. 49). A few centuries later, the Mendip lead-miners had special courts and laws of their own. Mr. Salzman, in his book on *Mediæval English Industries*, tells us that a miner who stole ore to the value of 1s. 1½d. was punished in the following way: his property was forfeited, and the bailiff was to bring him

> where hys howse or ore hys, hys work and towlls [tools] with all instruments belongyng to that occupacyon and then put hym in hys howss or working place and set fyer on all together about hym and banysshe hym from that occupacyon for ever before the face of all the myners there.

As for tin, it has long been thought that the Tin Islands, or Cassiterides, whence the Phœnicians obtained large quantities of this metal, may have been the British Isles, or rather that part of Great Britain which is now called Cornwall. Diodorus Siculus, writing about 30 B.C., says that the tin in the Cassiterides was produced in the promontory of "Bolerium" (? Cornwall) and carried over to the island of "Ictis" (? St. Michael's Mount, near Penzance), whence it was shipped to Gaul. Whether the Tin Islands were really Cornwall and St. Michael's Mount or not, we cannot be sure, but from the middle of the twelfth

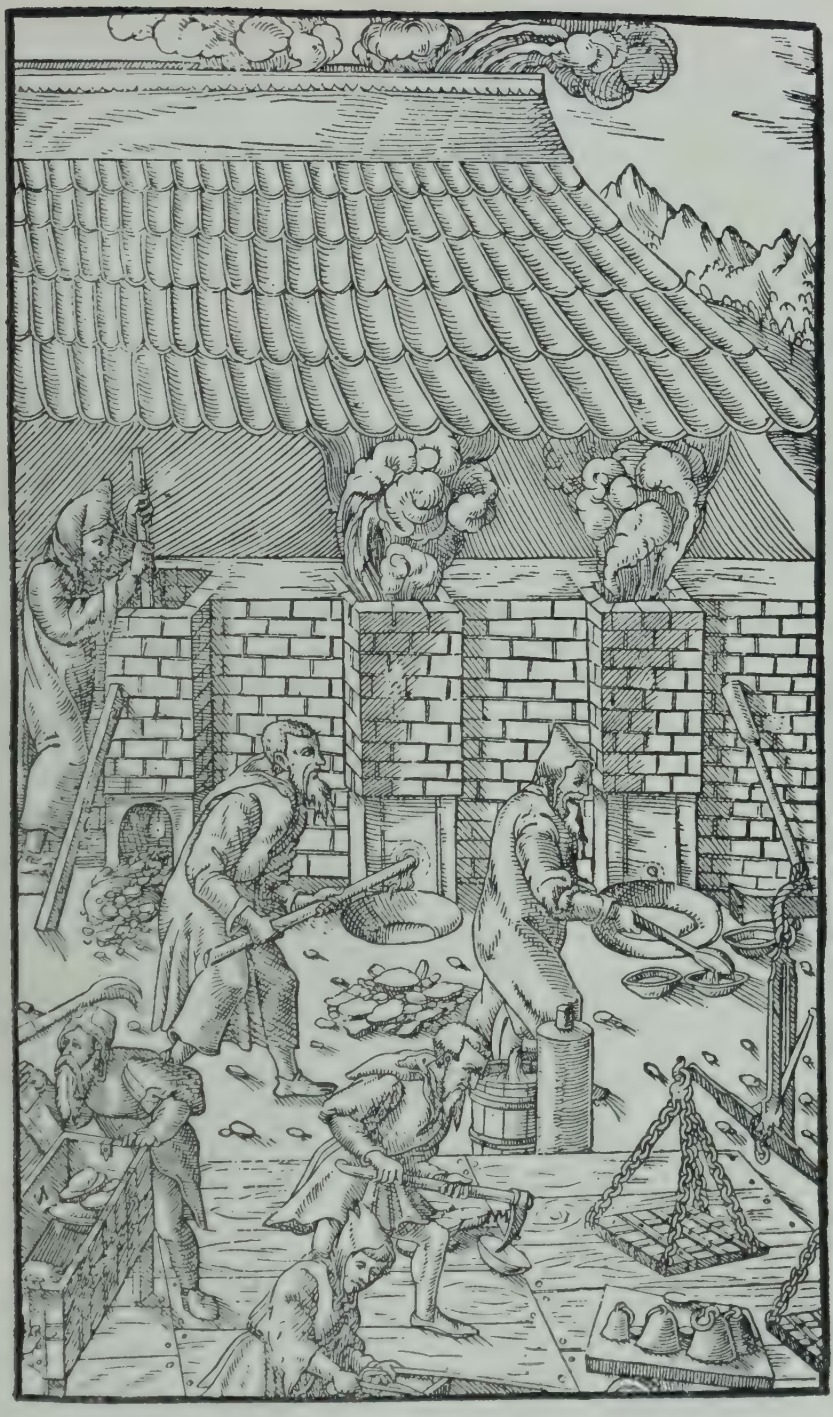


Fig. 38. Picture of Mediæval Mining Operations

century onwards tin-mining in Cornwall became a flourishing industry. Copper, however, seems not to have been mined in England on any large scale until the middle of the sixteenth century.

FIG. 39. PICTURE OF MEDIÆVAL MINING OPERATIONS

One of the most interesting books on mining, as practised in the Middle Ages, was written by George Agricola, a German scientist who lived from 1494 to 1555. It is called *De Re Metallica*, or "A Book about Metals," and Agricola was engaged upon it for over twenty years. For nearly two centuries it remained the standard book upon metals

FIG. 40. PICTURE OF MEDIÆVAL MINING OPERATIONS

and mining, and it was translated into German, Italian and possibly French and Spanish. This is remarkable testimony to the popularity of the book, for we must remember that, in the sixteenth century, every educated man could read Latin almost as well as his mother-tongue, so that there was not the same necessity for translation then as there is now. Agricola's book contains a great many very interesting wood-cuts, some of which have been reproduced here so that you may see the actual kind of machinery and tools used by miners nearly four hundred years ago.

How Metals are obtained from their Ores.—Since the days of Agricola, the use of metals has increased enormously, and many thousands of workers are employed in the industry at the present time. Most metals do not exist as such in the earth. They are usually found as their *oxides*, or compounds of the metal with oxygen. Iron, for example, is found as iron oxide in the mineral called *hæmatite*, of which vast quantities exist in Lorraine, the United States and Great Britain. Certain other metals are found as their carbonates, which consist of the oxide of the metal combined with the gas *carbon dioxide* which we have already studied. Copper, one of the most important metals to the modern, as to the ancient, world, exists as its oxide in the mineral *cuprite* and as its carbonate in the mineral *malachite*. Other common metallic ores are *sulphides*, which are compounds of metals with sulphur. Zinc, for instance, is found as zinc sulphide in the mineral called *zinc blende*.

Now it is clear that, to get metals from these minerals or ores in which they occur, we must remove the other elements which are present. Suppose, for instance, we have a metallic oxide, i.e. a compound consisting of a metal and oxygen. In order to obtain the metal we must devise a means of removing the oxygen. We can easily think of a way to do this if we reflect upon an analogy from daily

life. Let us imagine that you have a shilling and that, being a thrifty person, you are reluctant to part with it. Here the shilling corresponds to the metal, while you are the oxygen. In order to part you from your money what must be done? Well, there are several ways of causing this separation, but a very common way would be to exhibit to your gaze, in a shop window, something that you *very* much wanted and which cost a shilling: a "mine of serpents," for example, or a packet of luscious sweetmeats. If you wanted it sufficiently, you would cheerfully part with your

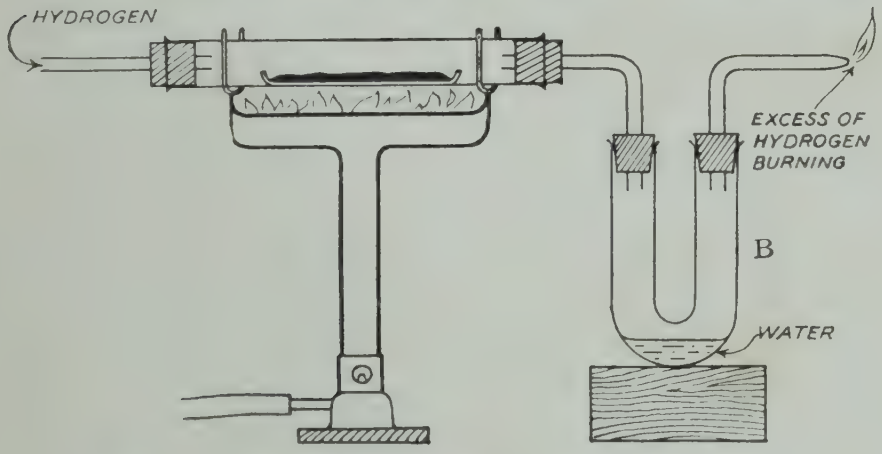


FIG. 41. CONVERSION OF LEAD OXIDE INTO LEAD

shilling. Now, how are we to apply this analogy to the separation of oxygen from metal in a metallic oxide? Clearly what we have to do is to offer the oxygen something which it prefers to the metal. As a matter of fact oxygen and hydrogen readily combine together, as we have already seen, so we may imagine that hydrogen has a great attraction for oxygen. Suppose we heat the metallic oxide in a stream of hydrogen: perhaps the hydrogen will combine with the oxygen, to form water, and leave the metal:

metallic oxide + hydrogen = water + metal

We can easily try this with some lead oxide. Let us put

some lead oxide in a porcelain boat, and then heat the latter in a stream of hydrogen in the apparatus shown in Fig. 41.

What happens? Well, we notice that after a time water collects in the U-tube B and that beads of metallic lead are left in the boat, so that our idea has proved successful. Many other oxides may be "reduced" to the metal in the same way.

Can we use this on a commercial scale? It is, of course,

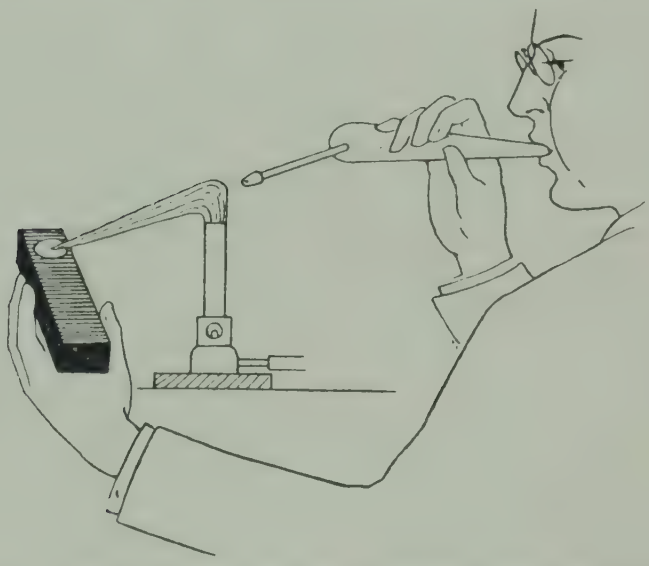


FIG. 42. REDUCTION OF LEAD OXIDE INTO CHARCOAL

possible, but hydrogen is rather expensive, so that in actual practice this method is not employed. It is necessary to use some cheaper substance which has a great attraction for oxygen. Fortunately such a substance is ready to hand. It is *carbon*. Coal, of which the world possesses vast stores, is mainly composed of carbon (anthracite, or steam-coal, for instance, contains 95 per cent. carbon), and carbon and oxygen very readily combine together to form carbon dioxide (p. 47). Hence we should expect that when a metallic oxide is heated with coal or coke—which is

nearly pure carbon—it will be reduced to the metal, and that the carbon will combine with the oxygen, forming carbon dioxide. You can test this for yourself, on a small scale, by heating some lead oxide on a charcoal block with the blowpipe (Fig. 42).

Scrape a little hole in a block of charcoal, place in it a little lead oxide, and heat the oxide by directing a blowpipe flame on to it. In a few minutes you will find little beads of lead in the hollow, while the lead oxide will have disappeared.

This method—reduction of a metallic oxide to metal by means of carbon—is the method which is generally employed in industry. The oxide, hæmatite, for example (p. 122), is mixed with coal and the mixture is then heated in a large furnace. The molten metal, being heavy, sinks to the bottom of the furnace and can be run off as desired, while the oxygen of the oxide, having combined with the carbon of the coal, goes off at the top of the furnace in the form of carbon dioxide.

If the metallic ore consists of a carbonate, this is first heated, when the carbon dioxide which was combined with the metallic oxide is driven off and the latter is therefore left. This is then reduced with coal as before. When the ore of the metal is a sulphide, it is often possible to convert this into the oxide by roasting it in a current of air, when both the metal and the sulphur combine with the oxygen in the air. The oxide of sulphur (sulphur dioxide) so formed is, you will remember, a gas and therefore goes off, while the metallic oxide is left. This may then be converted into the metal by heating it with coal in the usual way.

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CHAPTER VI

FIRE—HEAT, LIGHT AND ELECTRICITY

Vesuvius.—What boy or girl has not heard of Vesuvius and of the great eruption which, in A.D. 79, destroyed the cities of Pompeii and Herculaneum? Let us hear what Pliny the Roman, who escaped death himself, but whose uncle perished in the catastrophe, has to tell us about it. In a letter to his friend Tacitus, Pliny says that about one o'clock in the afternoon of the 24th of August his mother noticed a cloud of very unusual size and appearance. His uncle, the Elder Pliny, who was keenly interested in science, immediately walked up a hill close by in order to get a better view. He learnt later that the cloud consisted of smoke issuing from Mount Vesuvius, and ordered a ship to be prepared so that he could sail across the Bay of Naples and observe the eruption more easily. As the ship drew nearer, red-hot cinders fell into it, followed by pumice-stones and pieces of rock blackened, scorched and cracked by fire. Then the sea began to ebb away from underneath and the shore was blocked up by landslips caused by earthquakes. In the meanwhile night had come, and Mount Vesuvius was blazing in several places with spreading and towering flames, which appeared all the more terrifying by contrast with the surrounding darkness. Pliny's uncle landed again and went to visit a friend, who was naturally much alarmed at the eruption. The uncle, however, refused to be frightened, had his supper in the calmest way and then went to bed. Soon, however, the way to his room lay so deep under a mixture of pumice-stone and ashes that, if he had remained there any longer, he would not have

been able to get out. His friend aroused him, and they had a consultation as to what they should do. The house was now rocking to and fro as if torn from its foundations, so that they were afraid to stay indoors. In the open air, on the other hand, they dreaded the falling pumice-stones and cinders; yet they considered this the lesser danger: so they tied pillows upon their heads and went out. It was now day everywhere else, but in the country surrounding Vesuvius the darkness was blacker than that of the darkest night. The Elder Pliny and his companions decided to go down to the shore to find if they could possibly put out to sea, but they found that the waves were still extremely high. At last, Pliny's uncle threw himself down upon an old sail and drank goblet after goblet of cold water. Soon after, flames and a strong smell of burning sulphur put all his friends to flight. He himself, trying to get up with the assistance of two of his slaves, was overcome by the fumes and fell down dead. His body was afterwards found quite uninjured and still fully clothed; he appeared to be sleeping rather than dead. The Younger Pliny and his mother managed to escape, after a thrilling journey, the details of which you can read in Book VI. number 20 of his Letters.

What made this catastrophe all the more terrifying to the Romans was the fact that they had always regarded Vesuvius as an extinct volcano, and so were quite unprepared for an eruption. Since A.D. 79, Vesuvius has never been entirely quiet and has had many periods of great activity. Pompeii has now been very largely excavated, and from the remains we can get a very good idea of the character of a Roman town. Herculaneum, however, has not been excavated, since here the dust and the lava and pumice-stones became mixed with water and set hard to a rock-like substance; whereas at Pompeii they remained dry and friable and can therefore be easily dug away.

Fire-worshippers.—It is not difficult to imagine how the minds of ancient men must have been impressed by the sight of a volcano in action. Majestic, terrible and quite uncontrollable, men must have thought it the work of some awful god, and no one can be surprised to learn that many races of mankind became fire-worshippers. Even to-day the Parsees and the Brahmans worship fire, while in ancient Greece and Rome there were sacred fires which the people regarded with the greatest reverence. At Athens, for example, there was a golden lamp which burned night and day in the temple of the goddess Athena on the Acropolis. At Rome, a sacred fire was kept burning in the temple of Vesta; if it happened to be extinguished all business—both private and public—was stopped at once until it could be relit with the proper ceremonies. When Greek and Roman armies set out upon expeditions, they never crossed the frontier of their country without carrying an altar upon which burned a fire lit at the sacred fire in their capital.

Wonder at the beauty of the sun, and the realisation that man's life depends upon sunshine, led men in ancient times to become sun-worshippers as well as fire-worshippers. The Egyptians had scores of gods, but the chief of them all was Rē, the Sun-god. They supposed that at dawn Rē stepped into a ship called *Manzet*, "the ship of the day-break," in which he sailed across the heavens from east to west. At sunset, he stepped aboard another boat called *Mesenktet*, "the ship of the dusk," which bore him back from west to east during the night. Fire and light are, indeed, so essential to us, and even now we are such "sun-worshippers" and "fire-worshippers" in the sense that we love warmth and sunshine, that we cannot be very contemptuous of those early ancestors of ours who regarded "Sun" and "Fire" as real gods.

Aristotle and Fire.—Aristotle's "four elements," we know, were fire, air, earth and water. Three of these we have

already studied, so that we must now give some time to the last. Air, earth and water, we have found, all have weight, and can all be analysed into simpler substances, so that we no longer regard them as "elements." Fire, however, is of a different nature. In the first place, we see that "fire," to our modern minds, signifies *two* things, namely *heat* and *light*. We cannot imagine a fire which is not hot and which does not give out light, but we can easily think of things which may be hot and yet do not give out light, e.g. boiling water. Similarly, we know that some things can give out light and yet not be hot, such as a glow-worm or the luminous paint on our watches. It is true that most things which we use as sources of light are hot, and that most things which are very hot give out light, yet all of us know that heat and light are not identical. It seems, therefore, that in studying Aristotle's "fire" we shall have to regard it under these two headings of heat and light.

Heat

Temperature.—On a cloudless day in July, when the sun is blazing down upon us, we say, "How hot it is!" and in December, when the water in the jug in our bedroom freezes hard during the night, we say with chattering teeth, "*Isn't* it cold!" If anyone said it was cold on the July day or hot on the December day, we should look at him in amazement. Yet, if you will turn back to page 23, you will there find an experiment described which may cause you to reflect, and to think that perhaps after all it is not quite so easy to be sure what you mean when you say that a thing is hot or cold. The experiment was this. Take three bowls, one containing hot water, one containing very cold water, and one containing lukewarm water. Place one hand for a few minutes in the hot water

and the other in the cold; then put them both together into the lukewarm water. What do you find? Why, that one hand tells you that the lukewarm water is hot and that the other tells you it is cold. Now it cannot be both "hot" and "cold" at the same time, so we conclude that the skin of the hands is not a reliable instrument for telling us about the hotness or coldness of a thing.

Here, too, we have to consider a very important subject, viz. the difference between *amount of heat* and *temperature*. Suppose you took a saucepan containing a gallon of water from the tap and heated it over a gas-ring for five minutes. Suppose you then took a saucepan containing half a pint of water drawn from the same tap and heated it over the same gas-ring for the same time. Since it is the same ring and is used for the same time in each case, it is reasonable to suppose that it has given the same amount of heat to each saucepan. Now dip your finger into the water in each saucepan (if you dare!). Are both lots of water equally hot? Certainly not; the gallon of water is only warm, whereas the half-pint is practically boiling. Yet they were equally hot to begin with and have had the same amount of heat given to them! It follows, therefore, that one thing may contain far more *heat* than another and yet not be so *hot*.

To express *how hot* a thing is we say that it has a *temperature* of so many *degrees*, but we express the *amount of heat* it contains in a different way, about which we shall talk later. To get a clear idea of the difference between "heat" and "temperature," think of the people in a country — say England. Suppose there are 40,000,000 people in the country: this is its *population*. They are, however, not distributed evenly all over the country. In certain districts there is hardly one person to a square mile, while in others there are thousands. If an area of 300 square miles contains 9000 people, we say that the *density of its population* is 30 per square mile. Another area, of

30 square miles, might contain 1800 people; its density of population would thus be 60 per square mile. The second area, therefore, has a higher density of population than the first, although it does not contain so many people. In the same way, 100 c.c. of water may have a higher *temperature* than a litre of water, and yet not contain so much *heat*. If we have a "hot" body and a "cold" body and place them in contact with one another, we find that heat will pass from the "hot" to the "cold" body, in spite of the fact that the latter may possibly contain far more *heat* than the former. We say, in fact, that two things are at the *same temperature* when, if they are brought into contact with one another, no heat passes from either to the other.

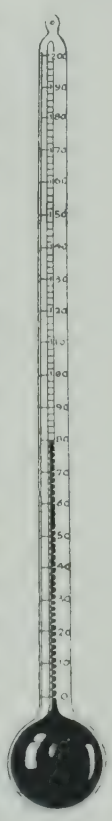


FIG. 43. THERMOMETER

Thermometers.—In order to measure the temperature of a body, we employ an instrument known as a thermometer. The ordinary thermometer makes use of the fact that when mercury, or quicksilver, is heated it *expands* or increases in volume. It consists of a thick-walled glass tube with a fine bore, blown out into a bulb at one end and sealed off at the other. The bulb, and part of the stem, contain mercury, and the rest of the stem is perfectly empty: it does not contain even air. In making the thermometer, the tube is prepared in this way and is then immersed in melting ice. After a time it is found that the level of the mercury-thread remains steady, and a mark is made on the stem at this level. Whenever the thermometer is put into melting ice, it will be found that the level of the thread is always at this mark, so we say that the temperature of melting ice is *constant*, and we call this temperature *zero* or 0°. The thermometer is then placed in a tube through which steam from boiling water is passed. The mercury expands, and its level in the stem rises until it reaches a

point at which it remains steady. This is the temperature of boiling water, and, like that of melting ice, it is always the same (if the atmospheric pressure, as shown by the barometer, is constant). The new level of the mercury is marked, and is said to show 100°. The distance between the zero mark and the 100° mark is then divided into one hundred equal parts, and the distance between any two of these marks next to one another is said to represent *one degree* (1°) of temperature.

A thermometer constructed on this principle is said to be a *Centigrade* thermometer, since it shows "100 steps," or degrees, between the melting-point of ice and the boiling-point of water. This is the kind of thermometer which is always used for scientific purposes, and for daily life in many countries. In Great Britain, however, the *Fahrenheit* thermometer is still commonly used for everyday purposes. On this instrument the melting-point of ice is called 32° and the boiling-point of water is called 212°, so that there are 180° between the two.

For temperatures below the melting-point of ice, the Centigrade "scale of temperature" uses −5°, −10°, −23° and so on; in other words, degrees with a *minus* sign in front of the number. Thus liquid nitrogen boils at −190° C., i.e. 190° below the melting-point of ice. The Fahrenheit scale of temperature goes down to 0° F. (32° F. below the melting-point of ice) and then uses degrees F. with a *minus* sign in front in the same kind of way as the Centigrade scale.

With a thermometer, then, we can measure *temperatures* accurately. If we place it in one liquid and it registers 55° C., and we then put it into a second liquid and it registers 55° C. again, we say that the two liquids are at the same temperature.

Amount of Heat.—Having settled what we mean by temperature, and having obtained an instrument for measuring it, we can now proceed to discuss what we mean

by *amount of heat.* Suppose we have 100 c.c. of water at 0° C. and we heat it to 50° C. We shall have put a certain amount of heat into the water. If we had taken only 50 c.c. of water at 0° C. and heated that to 50° C., we should have required only half the amount of heat. We assume, in fact, that, to raise the temperature of equal weights of water through the same range, we require equal amounts of heat, and in this way we can devise a method for measuring quantities of heat.

Unit quantity of heat, for scientific purposes, we take to be that amount of heat which is required to raise the temperature of 1 gram of water through 1° C. This unit is known as the *calorie.*

In daily life, two other units are often employed:

(i) *The British Thermal Unit.* This is the amount of heat required to raise the temperature of 1 lb. of water through 1° Fahrenheit. It is equal to about 252 calories and is shortly written B.Th.U.

(ii) *The Therm.* This is the unit of heat which gas companies employ for measuring the heat-value of the gas they supply to their customers. It is 100,000 B.Th.U.

Heat a Form of Energy.—A large proportion of the heat which is produced in the world is used for driving engines to do the world's work. Now, when a man does a lot of work, we say he is "energetic" or has "great energy," so you will not be surprised to hear that in science we define "energy" as "ability to do work." But before we know exactly what energy is, it is clear that we must know what scientists mean by *work.* Well, to put it shortly, we may say that work is done in a scientific sense when a body at rest is made to move, or when a moving body is stopped or has its speed altered. For instance, if I push at a truck and it does not move, I am doing no *scientific* "work," but if I move it, then I am "working." Similarly, if I stand in front of a cricket-ball which has just been hit, and I catch it, I have done a certain amount of "work."

And if a bicycle is moving along and I give it a push so that it goes faster, again I have done "work."

Energy, then, is that which can do work. There are several different kinds of energy. Electricity, for example, can drive a tramcar and is therefore energy. Heat, which drives a steam-engine, is another form of energy. Still another form is light, for light can be converted into heat; you will see in Chapter VII. that plants store up sunlight, and that when they are burnt this energy is given out again as heat. A moving body, again, such as falling water, can do work, as we saw in Chapter IV., so it possesses energy. This kind of energy, viz. the energy that a body possesses because it is moving, is called *kinetic energy*. Closely related to kinetic energy is *potential energy*, which is energy which a body possesses because it is in a certain position. For instance, the water in a tank at the top of a house could, if it were allowed to flow down to ground-level, work a water-wheel or turbine: hence it is said to possess *potential energy*. Lastly there is *chemical energy*, which we make use of in various ways, e.g. electricity from a dry battery is produced by chemical reactions between the sal-ammoniac and other substances in the battery.

Conservation of Energy.—What energy actually *is* we do not know. We know what it can do—work; and we can measure amounts of energy by finding out how much work is done. We know, too, that any one form of energy can be transformed into any other. Thus we can convert heat into electricity by making it drive a steam-engine which runs a dynamo, and we can convert electricity back again into heat by passing it through a thin wire, which soon becomes red or white hot, as in electric fires. We can also convert heat into light, as when we use a gas-flame to heat a mantle in an ordinary gas-burner. Kinetic energy, again, can be converted into heat, light or electricity, as when a waterfall is made to drive a wheel which

works dynamos from which electricity, and thence heat and light, can be obtained.

Most interesting of all, perhaps, is the fact that, so far as scientists have been able to discover, no energy is ever created out of nothing and none is ever destroyed; in other words, the total amount of energy in the universe is always the same. For instance, when a moving bullet, which possesses kinetic energy, is stopped by an iron target, the kinetic energy of the bullet is not destroyed: it is converted into heat. The target, and the lead of the bullet, become hot; and, indeed, the heat may be sufficient to melt the bullet. Since the target and bullet are now hotter than the surrounding air and the ground upon which they lie, they gradually give up heat to them until the temperatures are equal; but the heat is not destroyed.

In olden days, it was thought that heat was a material substance which had weight. It was called "caloric," but no one succeeded in isolating it! Then, at the end of the eighteenth century, Count Rumford, an American in the service of the Bavarian Army, was struck by the enormous amount of heat developed during the boring of cannon, and came to the conclusion that the source of this heat lay in the energy supplied to perform the boring. He conducted very ingenious and careful experiments to test his idea, and showed that heat could certainly not be a material substance like air, water or earth. In 1812 Sir Humphry Davy came to the same conclusion, and in 1849 Dr. Joule of Manchester successfully proved that heat is a form of energy, and was able also to calculate how much kinetic energy was equivalent to a calorie. The latter he did by letting known weights fall through a definite distance. By means of strings attached to the weights they were made to drive a stirrer in a vessel of water. This stirring made the water warm, and by measuring the rise in temperature and the weight of water taken, Joule calculated the amount of heat pro-

duced. This heat was derived from the kinetic energy of the falling weights, which Joule measured by observing the distance through which they had fallen. He was thus able to calculate the amount of mechanical energy equivalent to one calorie.

Light

Light is Invisible.—When you read the heading to this paragraph you were probably surprised, and perhaps you smiled to think that you had found a mistake in the book. However, it is not a mistake: light *is* invisible. You can easily prove this to your own satisfaction by watching a sunbeam falling into a room through a chink in the shutters. If the air is still and free from dust you can see where the beam enters and where it touches the floor or the wall, but you cannot see it in between. If, now, you brush the carpet of the room, or if you get someone to blow cigarette-smoke across the path of the beam, you will then see its course clearly. In other words, *light makes objects visible, but is itself invisible.* Had you ever thought of that before?

Light Travels in Straight Lines.—If you look again at your illuminated sunbeam, you will be able to see another interesting fact about light, viz. that it travels in a straight line.

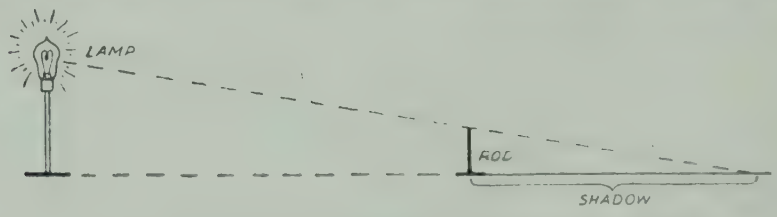


Fig. 44. Light Travels in Straight Lines

This, of course, you probably knew before. If, for example, there is a light at the end of a long straight passage, you can see it from the other end quite plainly, but if you go just round the corner it is cut off. If, again, you put a lamp

upon a table and set up a straight rod so that a shadow is cast, you will find that a straight line drawn from the tip of the shadow to the tip of the rod passes straight to the lamp.

Velocity of Light.—We said above that light *travels* in straight lines. Now, when you travel from one place to another, you go at a certain speed—say seventy miles an hour if you are in one of the big Great Western expresses. When we say that light "travels," do we mean that it takes a certain definite time to go a measured distance? The answer is yes; light *does* travel at a definite speed, and

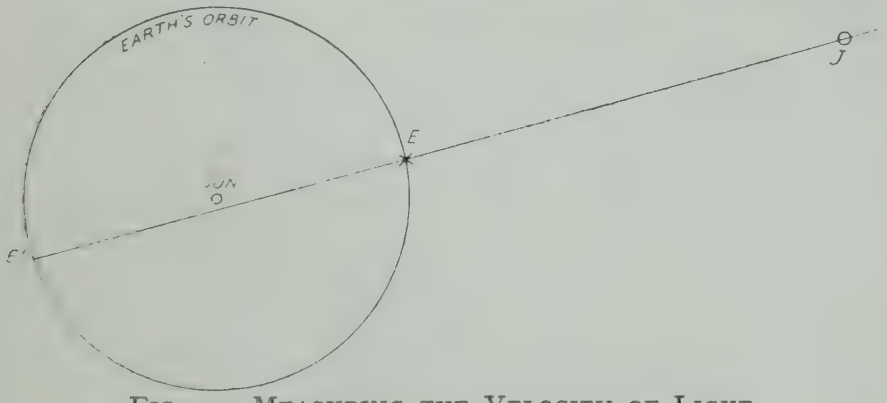


FIG. 45. MEASURING THE VELOCITY OF LIGHT

this speed has been measured. You may say that light must travel exceedingly fast, for if you light a lamp in a large room, the farthest corner appears to be illuminated instantaneously and you do not see the light gradually spreading through the room. You would, of course, be right; the speed of light is inconceivably great, being no less than 186,000 miles per second!

How can it be measured? This appears to be a very difficult problem, but it has been solved in several different ways. One of the easiest to understand is this. The planet Jupiter has several moons, and as they revolve around it they sometimes pass behind it, as seen from the earth, so that they are lost to view. Astronomers, by watching a

particular moon for a long time, can calculate exactly the time of the next occasion on which it will just be hidden behind the planet. Now we see objects because of the rays of light which leave them and travel until they strike our eyes. Jupiter's moons are so far away that it takes a comparatively long time (several minutes) for a ray of light leaving one of them to reach us upon the earth. Now, if you will look at the accompanying diagram (Fig. 45), you will see that sometimes the earth is upon the same side of the sun as is Jupiter, while at other times it is on the other side. When the earth and Jupiter are in the relative positions J, E′, the light from one of Jupiter's moons has to travel the distance E E′ farther in order to reach the eye of an observer upon the earth, than it has when the earth and Jupiter are in the relative positions J, E. Hence, if the time of the next occasion on which a certain moon of Jupiter appears to be just hidden by the planet is calculated for the position E of the earth, the disappearance of the moon *will appear to be late* if the earth is actually in the position E′. And the time it is late will be the time which the rays of light from the moon take to cover the distance E E′, which is the diameter of the earth's orbit. The length of this diameter is known; it is 195,000,000 miles. Astronomical observations have shown that, when the conditions described above are fulfilled, the time of the disappearance of Jupiter's moon behind that planet apparently is 16½ minutes late. Hence light must take 16½ minutes to travel 195,000,000 miles. Don't you think that the man who devised this method of measuring the speed of light was very ingenious? His name was Ole Römer; he was a Dane and was born in Jutland on the 25th of September, 1644. The paper in which he described his measurements of the speed of light was read to the Academy of Sciences at Paris on the 22nd of November, 1675. He died at Copenhagen on 23rd September, 1710.

Although light travels so quickly—it could go round the

equator more than seven times in a second!—it nevertheless takes many years to travel to us from most of the stars. Perhaps this fact, more than any other, will enable you to realise how very, very far away the stars are. Some are so distant that it takes over a thousand years for light to cross the space which separates them from the earth. In other words, if we had a telescope powerful enough to see events on the surface of such a star, what we should see would not be what was going on at the present time, but what had happened a thousand years ago! Even from the sun, which is the nearest star to us, light takes $8\frac{1}{2}$ minutes to reach us, so that if the light of the sun were suddenly to be extinguished we should not know until $8\frac{1}{2}$ minutes later.

Reflection and Images.—You all know the story of the young lady who looked into a curved mirror. She was surprised to see herself upside down and said to a friend, as if remarking upon the carelessness of the servants, "Look, they have hung that looking-glass the wrong way up!" She had evidently not studied the laws of reflection and did not know much about the formation of "images" by mirrors.

When a ray of light strikes a flat polished surface it is reflected, or "turned back," and the Arabs in the Middle Ages found that the angle that the ray makes with the surface on coming to it is exactly the same as that which the reflected ray makes with the surface (Fig. 46).

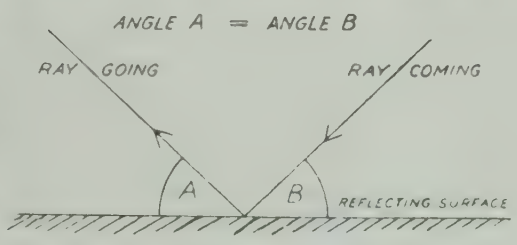


FIG. 46. REFLECTION AT A PLANE SURFACE

Now, we see a thing because of the rays of light which leave it and strike our eye. If you look at Fig. 47, you will see that the ray of light which is shown coming from the object O is reflected from the surface before it gets to the eye. That is, *to the eye* it appears to be coming from the

direction S O′, so that the object appears to be at O′ and not at O. This "appearance" of the object at O′ is called the *image* of the object, and, in the case of a flat mirror, it always seems to be exactly as far behind the mirror as the object is in front. You will have noticed, too, from looking at yourself in the glass, that your reflection is not quite the same as a coloured photograph would be, for in the glass, if you are holding something in your *right* hand, your image appears to be holding it in the *left*. To see why this is so, look at Fig. 48, which represents an object O, a mirror A B, and the image I of the object. If you trace the paths of the rays of light shown in the figure, you will see that the monocle which the object is wearing in its *left* eye appears in the image in the *right* eye. [N.B. In the figure it must be assumed that the object O, and therefore the image I, are standing upright, although they are necessarily shown in the plane of the paper.]

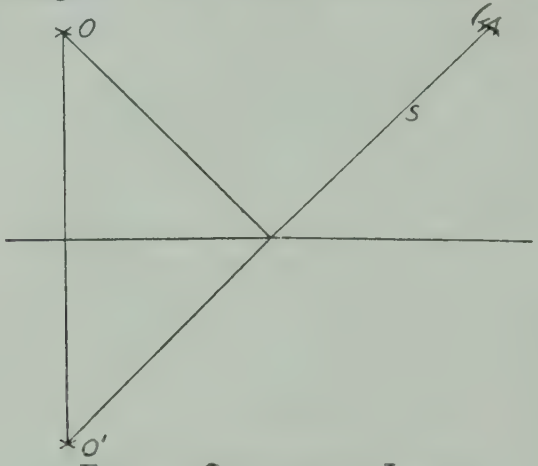


FIG. 47. OBJECT AND IMAGE

In the case of hollow (*concave*) and bulging (*convex*) mirrors, the images appear reduced or magnified or distorted. Why this is so, you will learn later on in your science course; meanwhile, from your work on *plane* or flat mirrors, you will be able to understand, for instance, why the dog in the fable was deceived when he looked into the pool and saw another dog there whose bone he tried, with disastrous results, to get!

Refraction.—When you poke a straight stick into a pool of clear water it appears to be bent, but when you take it out again it is still quite straight. Now we do not believe

that the mere fact of putting a stick into water can bend it, yet it certainly *looks* bent. We therefore assume that the *rays of light* which come from the part of the stick in the water are bent. Experiments made to test this idea have shown that it is correct, and that, in fact, all rays

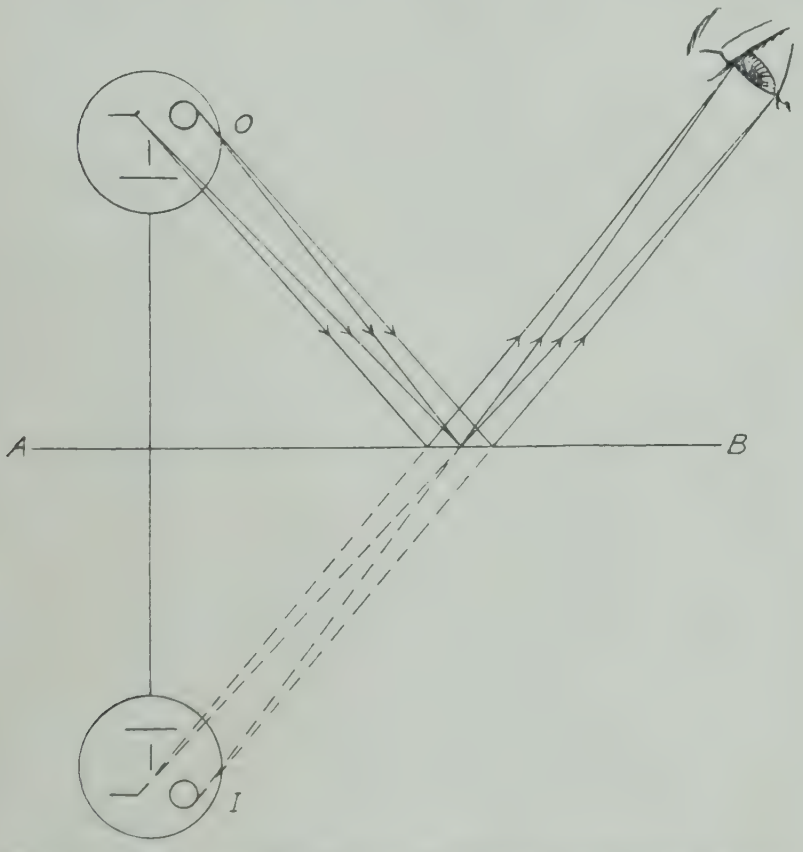


FIG. 48. WHY AN OBJECT IS REVERSED WITH ITS IMAGE

of light which, passing from air into water, strike the water at a slant are bent down away from the surface of the water (see Fig. 49). In the same way, if a slanting ray passes *from* water *to* air, at the surface of the water it is bent *towards* the surface. If, instead of water, we use glass, the same kind of *refraction* or bending of the rays takes place.

You may carry out a very interesting experiment on refraction in the following way. Take a pudding-basin and at the bottom of it place a shilling. Then move your head away from the basin until the coin is *just* hidden by the edge. While you are in that position, get someone to pour water into the basin. Perhaps you will be amazed to find that you can now see the coin! The explanation is simple if you remember what has just been said about refraction. Look at Figs. 50 and 51. The ray A B, which is, so to speak, the end one of all those coming from the coin which can get past the edge of the basin, passes straight on along B C and just misses your eye. Any other ray, such as A E F, is farther still away from the eye, and so the coin cannot be seen. Now, when the basin is filled with water, all the rays which leave the water in a slanting direction get bent down towards its surface. Hence the ray A E F, which follows its original direction as far as E, is bent in the direction E F′ afterwards and so reaches the eye, which therefore sees the part of the coin from which the ray started, viz. the farther edge.

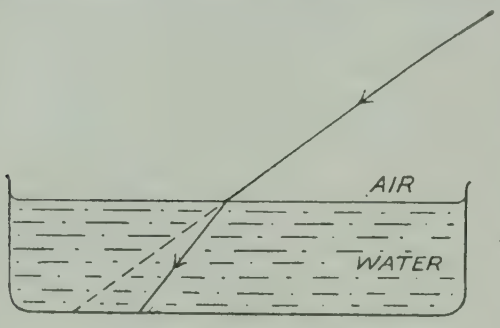


FIG. 49. REFRACTION OF A LIGHT-RAY PASSING FROM AIR INTO WATER

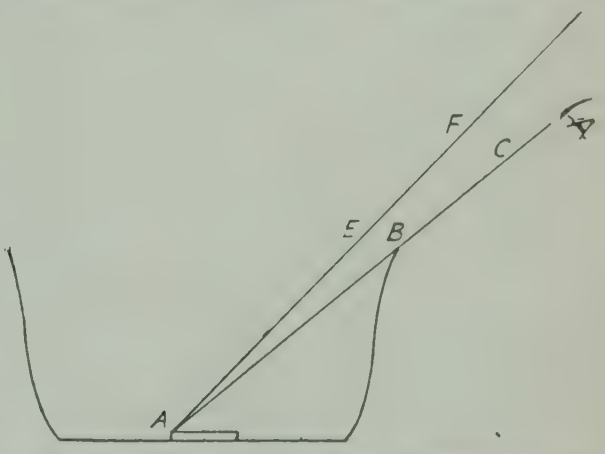


FIG. 50. EXPERIMENT ON REFRACTION

Lenses.—If we pass a ray of light through a rectangular

glass block, we find that it is bent twice, once on entering the glass and once on leaving it (see Fig. 52). When it enters, it is bent *away* from the surface of the glass, and when it leaves it is bent, just as much, towards the surface, so that after it has passed right through it is in a direction parallel to its original one. Now, if we take a piece of glass bulging or convex on both sides, what will happen to rays of light passing through it? They will of course be refracted on entering it and on leaving it, and if the convex surfaces are parts of a sphere, a remarkable thing may happen—the rays of light may be bent so that they all pass through one point, which is called the *focus* of the lens. If you have a convex lens—an ordinary magnifying-glass, for instance—you can easily find its focus on a sunny day by holding the lens between the sun and your hand, and moving it up and down till you get the tiniest possible image of the sun upon your skin. This image is at the focus of the lens. You will find at the same time that the heat rays also are focussed to that point!

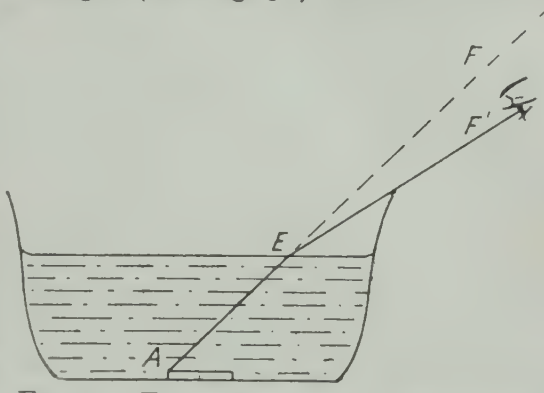


FIG. 51. EXPERIMENT ON REFRACTION

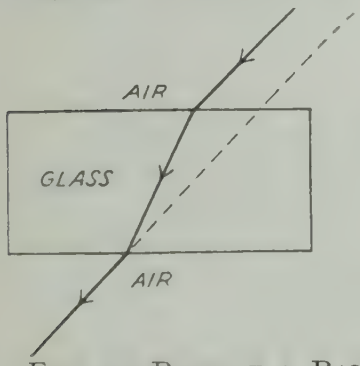


FIG. 52. PATH OF A RAY OF LIGHT THROUGH A RECTANGULAR GLASS BLOCK

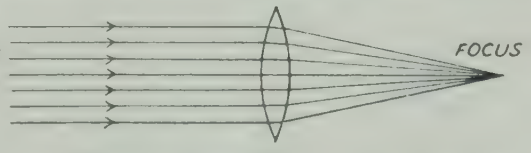


FIG. 53. FINDING THE FOCUS OF A CONVEX LENS BY MEANS OF THE SUN

Magnifying-glasses.—Your convex lens, if held at a

certain distance above an object, makes it appear larger. Now, just as you knew that the stick in the water was not really bent, so you know that the object you are looking at is not really any larger when it is under a convex lens. What you see, in fact, is *not* the object itself, but an image of it. The images formed by a convex lens differ from those formed by a plane mirror in this respect—that you can sometimes actually get them upon paper, whereas this is impossible with the image given by a plane mirror. You have probably discovered this for yourself, by standing as far back as possible from the window in a room and getting an image of the window on a piece of paper by means of a magnifying-glass—only in this case the image is *smaller* than the object.

It is a simple matter to understand how a lens produces an image if you remember two things: (*a*) that all rays which pass directly through the centre of the lens are not bent, and (*b*) that all rays which strike the lens in a direction parallel to a line (called the *axis* of the lens) drawn through the centre of the lens perpendicularly to its convex surfaces, pass through the focus of the lens. Hence, suppose we have a convex lens, the centre of which is C, and an object A B in front of it.

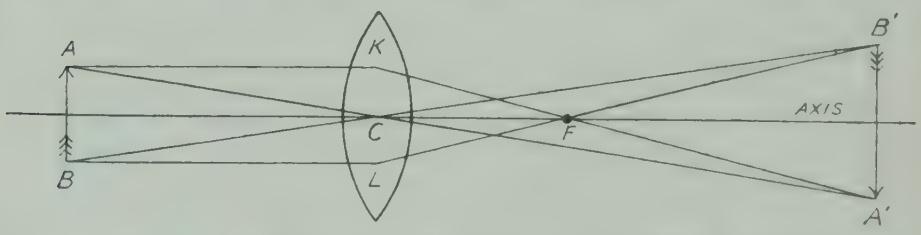


FIG. 54. FORMATION OF IMAGE BY CONVEX LENS

Let us trace the paths of two rays of light from each end of the object, one ray from each end passing through the centre of the lens and one striking the lens in a direction parallel to its axis. Let F be the focus of the lens. Then the ray A C, since it passes through the centre, will not

be bent, and will pass straight along in the direction C A′. Ray A K, being parallel to the axis, passes through the focus F. Similarly the rays B C and B L, after passing through the lens, meet at B′. To an eye farther to the right of the diagram, all rays really coming from A would therefore *appear* to be coming from A′, and all rays coming from B would *appear* to be coming from B′. Hence the object would *appear* to be at A′ B′. In other words, at A′ B′ we have an *image* of the object magnified and turned upside down. If we put a sheet of white paper at A′ B′ we should see the image upon it.

By drawing a figure with the object a long way away from the lens, you can satisfy yourselves that, in this case, the image would still be upside down, but would now be *smaller* than the object.

When you use a convex lens as a magnifying-glass, the conditions are not quite the same as those we have been studying. If the object is nearer to the lens than is the focus, we find that the image can no longer be got on to a

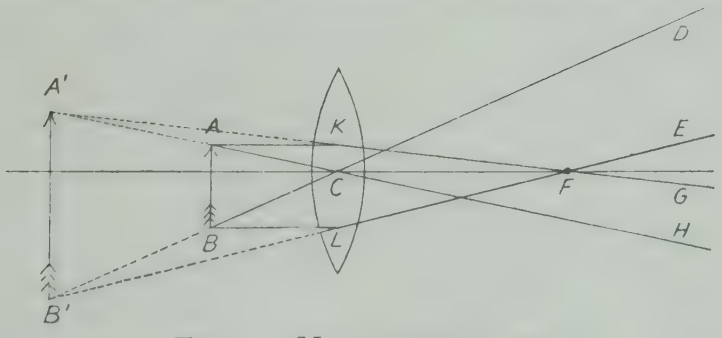


FIG. 55. MAGNIFYING-GLASS

piece of paper; we say, in fact, that it is a "virtual" image, while in the opposite case we say that the image is real. To see what happens when you use a magnifying-glass, look at Fig. 55.

Here you will see that the distance from the lens to the object A B is less than that to the focus F. Taking two rays A K and A C from the end A of the object, and two

rays B L and B C from the end B, you will see that after passing through the lens A K and A C they go in the directions K F G and A C H respectively; similarly B L goes in direction L F E and B C in direction B C D. Hence, to an eye on the right side of the diagram, it *appears* as though K F G and A C H both come from A′, and L F E and B C D from B′. Therefore the eye sees the image A′B′, but it is not a *real* image because the rays of light do not *actually* pass through it; they only *seem* to do so. In a real image, as shown in Fig. 54, the rays of light really *do* pass through the image. In Fig. 55 the dotted lines show the apparent paths of the rays of light.

A Camera.—In a camera advantage is taken of the fact that a convex lens gives a real image if the object is farther from it than the focus. The lens is made to cast this image upon a plate of glass or a film at the back. The film or plate, as the case may be, is covered with a layer of gelatine which contains a compound called *silver bromide.* This is sensitive to light, which turns it purple. To observe this, take a solution of silver nitrate and another of potassium bromide and mix them. You will get a yellow solid formed which is silver bromide. If you expose this to sunlight for some time it will gradually go purple. Silver chloride behaves in the same way.

Now, when the image is thrown upon the plate, the bright parts of it cause some of the silver bromide to decompose into metallic silver; the dark parts do not affect the plate; while those portions which are intermediate in brightness cause the corresponding amount of decomposition of the silver bromide. The plate is then placed in a solution of a mixture of chemicals called the developing solution. These chemicals continue the conversion of silver bromide into silver, but they can act only where this conversion has already been started by the light. The more the effect of the light, the greater the effect of the developer, so that very soon the image appears in black and yellow, the

blackest parts being those which were, in the original image, the most brilliantly illuminated. When the image on the plate is sufficiently thick, the developing is stopped and the plate is placed in a solution of "hypo" (sodium thiosulphate), which dissolves out the remaining silver bromide but has no action on the metallic silver. After washing and drying, the plate is now finished. On it there is a reproduction of the image which was cast upon it by the lens, but it is a *reversed* image in two senses: (*a*) it is upside down and the wrong way round, and (*b*) it is dark where the original image and object were light, and light where they were dark. When, however, this "negative" is placed against a piece of paper, the surface of which is covered with a layer of gelatine containing silver chloride, in such a way that the coated sides of both plate and paper are together, it is clear that, on exposing the arrangement to light, the image formed on the *paper* will be the right way round and will also be dark where the object was dark and light where it was light. The paper is allowed to darken until the picture is rather darker than is required, and is then treated with "hypo" to remove the unchanged silver chloride. After this it is washed and dried and there is the photograph.

The Eye.—The eye is, in essentials, a kind of camera. It has a lens in the front which casts an image of whatever is before it upon a "screen," called the *retina*, at the back. The retina is richly supplied with nerves, and in some way these are able to tell the brain about the image in the eye, and thus we "see."

Colour.—Suppose you allow a sunbeam to enter a darkened room through a hole in the shutter, and to strike the opposite wall. You will have a spot of white light on the wall. If now you put a glass prism in the path of the beam, instead of getting a white spot on the wall you will get a band of coloured light, red at one end and then passing successively through orange, yellow, green, blue

and indigo to violet at the other end. This remarkable fact, which was discovered by Sir Isaac Newton, is explained by assuming that ordinary white light is made up of light of these various colours. The band of coloured light is called a spectrum. With the assistance of this knowledge, it is not difficult to explain why some things appear blue, others red, and so on. A blue book, for example, is blue because, of all the daylight which falls upon it, it absorbs or takes up *all except the blue*; this it reflects to our eyes and so it looks blue. Similarly, a cricket-ball is red because in its leather there has been placed a substance which absorbs light of all colours except red, which it reflects. Suppose we looked at a blue book through red glass: What colour would it be? Well, only *red* rays can get through red glass, and the book is giving out only *blue* rays. Hence no light can reach us from it through the red glass and it therefore appears black. Try this for yourselves.

Now, when we talk about light of different colours, we must remember that light, as we saw on p. 136, is really invisible, so that what we mean when we say, for example, "blue light" is light which, when it enters our eye, produces the sensation of blueness. In other words, colour is merely a *sensation* or feeling in our brains, so that it follows that a coloured substance is not *coloured* when no one is looking at it! It is, of course, still giving out its own peculiar variety of light, but there can be no colour, which is a sensation in the brain, unless there is a brain there to have the sensation! See what your friends say when you tell them that a lemon is not yellow when no one is looking at it!

Electricity

The Lodestone.—Far away in Asia Minor, in a country known as Magnesia, there is found a black heavy mineral which is called the "lodestone." Even in ancient times it was observed that this stone had the remarkable property

of being able to pick up and attract pieces of iron, and men who wished to mystify their fellows often exhibited the lodestone and displayed its powers. Exaggerated stories of all kinds grew up, and those of you who have read the *Arabian Nights* will remember the tale in which it is related that a ship, having ventured too close to a whole mountain made of lodestone, had all its iron nails dragged out by the force of attraction, so that it foundered. From the fact that the lodestone was found chiefly in the country of Magnesia, it came to be called the *Magnetic* stone, whence our word "magnet." The other name of the mineral, "lodestone," really means "leading-stone," and was given to it for the following reason. If a lodestone is suspended by a thread, or floated on a piece of wood upon water, it always turns in such a direction that a definite point of it faces to the north. That is, if the stone is allowed to come to rest and a mark is made upon that point of it which faces north, and the stone is then displaced and allowed to come to rest again, it will be found that the point which originally faced north is again facing in that direction; and this happens every time the stone is displaced and allowed to set itself freely. This property of the lodestone was discovered many hundreds of years ago, and was applied, in the instrument known as the *compass*, to guide ships across the trackless ocean: hence the name "leading-stone."

Magnetising Iron. — Another interesting property of the lodestone is that, if a piece of steel or cast-iron is rubbed with it, the steel and iron themselves become converted into magnets. They can then attract iron like the lodestone itself, and will also set themselves in a definite direction if they are free to move. Since a lodestone is generally of a very irregular shape, whereas an iron magnet can be made in the form of a straight bar, it is more convenient to study the properties of a magnet, that is "magnetism," with the latter.

Properties of a Magnet.—Suppose we take a bar-magnet and suspend it horizontally by a loop of thread (Fig. 56), so that it can swing in either direction in a horizontal plane. Let us make a mark upon one end, so that we may know this end from the other. Then we shall find that, however much or however many times we displace the magnet, it will always return at length to such a position that one end is pointing approximately north and the other approximately south. We shall find, too, that it is always the *same* end which points to the north; if we swing the magnet round so that the other end points to the north it will immediately right itself as soon as we let it go.

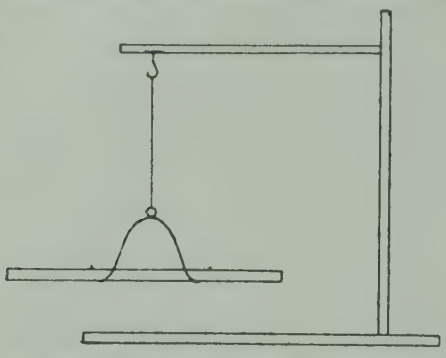


FIG. 56. BAR-MAGNET SWINGING IN A HORIZONTAL PLANE

Now let us put the magnet into a heap of iron filings, and then lift it out again. It brings many of the filings with it, but what we notice particularly is that the filings are thickest round two points, close to the ends (Fig. 57). These two points, the position of which we can guess roughly from the bulk of the filings which surround them, are called the *poles* of the magnet. Every magnet, whether its shape is regular or not, has two poles, and it is found by experiment that, when the magnet is allowed to swing freely in a horizontal plane, as in the experiment described above, it always comes to rest in such a way that the line joining the two poles is approximately north and south. That pole which points towards the north is called the north-seeking pole, and is generally marked "N" on an ordinary magnet.

FIG. 57. BAR-MAGNET AND IRON FILINGS

We can get further information about the properties of a magnet by suspending a bar-magnet in a loop as before and bringing up towards its N-pole the N-pole of another magnet. We shall find that the N-pole of the magnet which is free to move swings *away* from the N-pole of the other. Similarly, we find that the two south-seeking poles repel one another. On the other hand, if we reverse the procedure and bring the S-pole of our magnet near to the N-pole of another, we see that they *attract* one another; so much so that if we let them touch we may have to exert a fairly considerable force to separate them. These important facts may be summarised in the words:

Like poles repel one another; unlike poles attract one another.

Terrestrial Magnetism.—The behaviour of like and unlike magnetic poles enables us to see a very simple explanation of the mysterious power of a compass. The simple compass consists merely of a magnetised needle free to swing round, in a horizontal plane, on a pivot (Fig. 58). It comes to rest, as we know, with its north-seeking pole towards the north and its south-seeking pole towards the south. Suppose, now, that the earth is a huge magnet. It is clear that the north-seeking pole of the compass-needle would be attracted by the one magnetic pole of the earth and repelled by the other; the needle's south-seeking pole would be similarly affected, only in the opposite way. Thus the needle would come to rest in such a position that the line joining its poles was in the line joining the two magnetic poles of the earth drawn through the position on the earth's surface in which the compass happened to be at the time.

FIG. 58. COMPASS-NEEDLE

This explanation covers the facts very well, and also agrees with a great many more facts which we cannot discuss in this little book. The earth, indeed, is an enormous

magnet. Its north magnetic pole is near the north geographical pole, but the two do not quite coincide; the same is true for the south poles. Hence, when steering a ship by compass, the captain has to make allowance for the fact that the needle is not pointing exactly to the true north and south.

A Magnetic Field.—If we take a bar-magnet, place it under a sheet of paper, and then sprinkle fine iron filings on to the paper, we shall find that—especially on tapping the paper slightly—the filings arrange themselves in a regular way (Fig. 59). All round the magnet there are *lines of magnetic force*, and the filings set themselves in the position of those lines of force which pass through the paper. Exactly what these lines of force are we do not know, but they spread out from every magnet in all directions. Near the magnet they are close together; farther away there are not so many of them in the same space. A space through which lines of force are passing is called a *magnetic field*, and the more lines there are in a given space the stronger the field at that point. Near a magnet the field may be very strong.

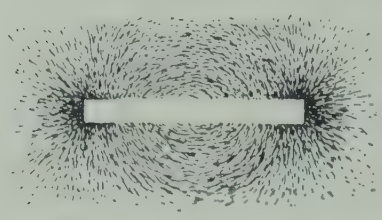


FIG. 59. A MAGNETIC FIELD

Electricity.—If you take your fountain-pen, warm it in front of the fire to make sure it is perfectly dry and then rub it vigorously upon your sleeve for some time, you will find it has acquired the strange property of being able to pick up little bits of paper. If you can get a vulcanite rod (vulcanite is the stuff of which your fountain-pen is made) and rub it hard with a piece of fur, you will be able to make it show this property in a very marked degree. Similarly, a glass rod rubbed with silk will pick up light objects.

Now take a piece of pith suspended by a hair from a stand, and bring the rubbed vulcanite rod near it. You will find that the pith is attracted and, if you hold the rod

near enough, the two may touch. The moment this happens the pith is strongly repelled!

What is the explanation of these strange events? Well, if you will refer to p. 111, you will see that scientists have found that all matter is composed of two kinds of tiny particles: electrons and protons. These particles are particles of electricity, which is therefore of two kinds, viz. that consisting of protons, which is called positive electricity, and that consisting of electrons, which is called negative electricity. When a body contains more protons than electrons it is said to be *"positively charged"*; when it contains more electrons than protons it is said to be *"negatively charged."* Now, when you rub the vulcanite with the fur, what you do is to remove some of the electrons from the atoms in the fur and give them to the vulcanite, so that the latter becomes *negatively charged*, while the fur itself, now having more protons than electrons, is *positively charged*.

Just as a north magnetic pole attracts a south pole, while two north poles, or two south poles, repel one another, so it is found that two charges of the same kind of electricity repel one another, while a positive charge attracts a negative one. When you held the negatively-charged vulcanite rod near the piece of pith, the pith was at first attracted, showing that electrified bodies attract unelectrified ones. When the pith *touched* the rod, however, we may suppose that some of the electrons passed from the rod on to the pith, which therefore itself became negatively charged and therefore was repelled from the rod.

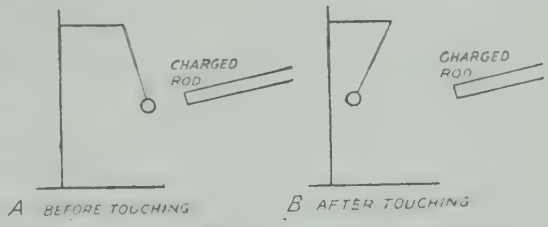


FIG. 60. PITH BALL AND CHARGED ROD

When a piece of glass is rubbed with silk, it becomes positively charged, while the silk becomes negatively

charged; in other words, electrons are rubbed *off* the glass *on* to the silk.

Conductors and Non-conductors.—If you hold a copper rod in your hand, however vigorously you rub it with fur you can never charge it with electricity. If, however, you have the rod mounted in a glass handle, you can easily charge it with negative electricity by rubbing it with a cat-skin in the usual way. Suppose you now touch the charged rod with your hand and then test it with a pith ball, as in Fig. 60. You will find that the charge has disappeared. If, again, you touch the charged rod with a piece of glass, it remains charged, but if you touch it with a metal rod or wire it loses its charge at once. The explanation of this interesting fact is that electricity can move along some substances, but not along others. Substances which allow electricity to flow along them are called *conductors*; those which will not are called *non-conductors* or *insulators*. Metals, coke and the human body are very good conductors, and so are solutions of acids, bases and substances like salt or copper sulphate. Some bad conductors or good insulators are china, wool, silk, sealing-wax, vulcanite, glass, india-rubber and candle-wax. Hence, when you touched the charged copper rod with your hand, all the electricity flowed away from it through your body into the earth.

Currents.—When electricity is being conveyed from one place to another along a conductor, e.g. a copper wire, we say that an *electric current* is passing through the conductor. In 1819, it was shown by a Danish scientist named Oersted that if a wire carrying an electric current is held above a compass-needle, originally pointing, as usual, north and south, the needle is turned to one side (Fig. 61). A few years later, the French physicist Ampère reinvestigated this matter, and showed that the direction in which the needle was turned or "deflected" could easily be remembered by the following rule:

If a man were swimming in the wire in the direction of the current, with his face towards the compass-needle, the north pole of the latter would be turned towards his left-hand side.

If, therefore, we bend the wire round underneath the needle and then above it again, and so on, you can easily see that, since the current is flowing in the opposite direction underneath from that in which it is flowing above, the parts of the turns below will help to turn the needle in the same direction as those which are above. The greater the number of turns the greater the effect upon the needle.

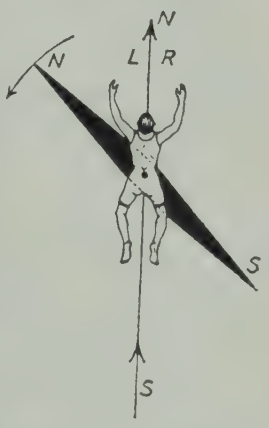


FIG. 61. AMPÈRE'S RULE

This phenomenon is used in various ways in everyday life. In the first place, it is often used to detect and to measure an electric current. If we think a wire is carrying a current, we can easily make certain by holding the wire above a compass-needle; if the needle is deflected there is a current in the wire. Moreover, the stronger the current the greater the deflection, so that with instruments ("galvanometers") constructed on this principle we can both ascertain the presence of a current in a wire and also find out how strong it is.

Secondly, the effect of a wire carrying a current upon a compass-needle is used in the telegraph instrument. This consists, in principle, of a compass-needle surrounded by a coil of wire through which a current can be passed in either direction. When it is passed in one way, the needle is deflected to the left; when it is reversed, the needle is deflected to the right. When there is no current at all, the needle is not deflected either way. By letting a certain number of deflections to the right or left, or both, signify a particular letter of the alphabet, it is a simple matter to send messages from one place to another. All that is necessary is the compass-needle surrounded by its coil

of wire at one end, a wire connecting the two places, and an arrangement for sending an electric current through the wire, in one direction or the other, at the other end.

Electro-magnets.—It was discovered by William Sturgess, about a hundred years ago, that if a coil of wire carrying an electric current is wrapped around a piece of iron, the iron becomes a magnet. If the iron is of the kind known as "soft iron," it loses its magnetism as soon as the current is switched off. Here again the more powerful the current, the stronger the magnetism produced. By winding a long length of wire around the iron and using a strong current, "*electro-magnets*" of tremendous strength have been made. They are very largely used in ship-building and in other industries where heavy weights of iron have to be moved from one place to another. You will see one illustrated in Fig. 62.

FIG. 62. A BIG ELECTRO-MAGNET

Circuits.—We have seen that electricity consists of electrons and protons. An electric current is really a migration of electrons from one place to another. Now, if there is no place for the electrons to go to, they stay where they are, and no current flows. Suppose, for instance, that we had a copper rod mounted upon a glass stand. We could charge it with negative electricity by rubbing it with fur, but there would be no *current* in it, for the electrons cannot pass through the glass stand and so have

to remain where they are. In a battery or dynamo, used to produce electricity, what happens is this. From one part of the instrument a supply of electrons can be obtained, while at another there is a place where they can be taken in again. If those two parts are joined by a conductor, a flow of electrons, or an electric current, passes through the conductor, the electrons leaving the one part and flowing along the conductor to the other. Hence you will see that to get an electric *current* you must have a complete circuit from the one part of the battery or dynamo right back to the other. Now, when talking about the electric telegraph, we said that *a* wire was necessary to connect the two places. Should it not have been *two* wires—one to take the electrons and the other to bring them back again? Well, one would naturally think so, but as a matter of fact the *earth* is a very good conductor, so that is used instead of a second wire, as shown in Fig. 63.

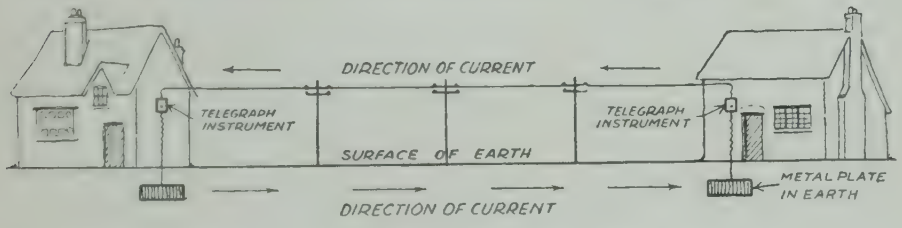


FIG. 63. USE OF EARTH AS CONDUCTOR

Electrolysis. — When we were talking about water (p. 72), we saw that when an electric current is passed through salty water the water is split up into hydrogen and oxygen. This process is called electrolysis. If a *strong* solution of salt is used, the salt itself is split up instead of the water, and chlorine comes off at the anode (p. 73). The other constituent of salt, viz. the metal sodium, is set free at the cathode, but it immediately acts upon the water present, forming hydrogen, which comes off, and a slimy substance called caustic soda, which remains in solution.

If we electrolyse a solution of copper sulphate, using a copper instead of a platinum anode (p. 73), we find that the net result of the action is that the current transfers copper from the anode to the cathode, the former getting lighter and the latter heavier. The same kind of thing happens if we electrolyse a solution of a silver compound, using a silver anode. This fact is made use of in copper-plating and silver-plating. The object to be silver-plated, for example, is hung in a bath of a solution of a silver compound, and is made the cathode, while the anode consists of a block of silver. On passing the current, silver is dissolved from the anode, carried through the solution and deposited as a coating upon the cathode, which is thus *silver-plated.*

Aristotle again.—Now we have considered all of Aristotle's four elements in a brief manner, and we have also glanced at some facts concerning electricity. Aristotle, however, was interested in living things as well, and we cannot do better than to follow his example again, and spend some time in studying Life.

CHAPTER VII

LIFE

What is meant by Life?—Although we should not find any difficulty in deciding whether a dog or a cat was alive or not, and although the fact that a stone is not alive is obvious, yet we may not have stopped to ask ourselves the question, "How do we decide whether a given thing is living or not living?" So, before we set out to talk about living things in general, let us devote a few minutes to a consideration of this problem. First of all, in what ways do living things differ from others? If you think for a moment, you will probably come to the following conclusions:

(i) Living things can move about from place to place of their own accord.

(ii) They require food.

(iii) They breathe.

(iv) They produce young ones or seeds which grow up into animals or plants of the same kind as those which gave rise to them.

Suppose we take each one of these characteristics in turn.

Living Things can Move.—This is true of animals in general, but there are some animals which are fixed, such as sponges. Plants, again, although they are certainly alive, usually remain fixed in one spot. Hence we cannot go by this characteristic alone; we must have regard also to the others.

Living Things require Food and they Breathe.—Here we have a test which will prove more useful than the last, for no living thing, be it plant or animal, can exist for long without food or without breathing. How most animals

get their food is well known: they eat and they drink. Plants, however, feed in a different way, which we shall discuss later on (p. 175). It is clear, meanwhile, that they take up some food through their roots, for otherwise there would be no object in manuring the ground. That animals breathe, again, is a fact with which everyone is familiar, although here too there are some interesting peculiarities worth special study. It is not so obvious that plants breathe, for they have no lungs or gills, and in order to show that they really do breathe it is necessary to make careful experiments. Still, if it is found that a certain object feeds and breathes, there is no doubt that it is alive. Similarly, if we can be perfectly sure that another object does not breathe or feed, we know that it is not alive.

Living Things produce Offspring.—Another characteristic feature of living things is that they give rise to other individuals of the same kind. We have seen (p. 55) that a single bacterium can give rise to many million bacteria in the course of a single day, and anyone who has kept mice or rabbits knows the astonishing rapidity with which they multiply. A single poppy, again, may produce thousands of seeds, while the number of eggs laid by a single herring is amazing. This power of reproduction is not possessed by non-living objects. Living things have still another property which is not shared by those not alive, namely, they can *grow*. We should be very surprised if we found that, during the night, a small lamp-post had grown into a large one, or if it had given rise to several young lamps!

The features, then, we look for to enable us to distinguish between those things which are alive and those which are not are:

(i) Power of movement, of growth, and of reproduction.
(ii) Living things feed and breathe.

Differences between Plants and Animals.—Just as it is easy in most cases to distinguish between living and non-

living things, so it is generally a simple matter to decide whether a living object is a plant or an animal. You would, for example, not make the mistake of calling a cabbage an animal or a lion a plant, but the problem becomes more difficult when you consider lowlier forms of life, such as the corals and sponges. Let us consider then, first of all, the main features which make it convenient for us to group plants in one kingdom and animals in another. One of the most obvious differences between plants and animals is that, generally, the latter can move from place to place, while the former are fixed. But we must remember that some animals, like the sponges and corals mentioned above, are fixed to one spot, while some plants, especially the very tiny green *Algæ* (p. 181), which live in water, can swim about.

Next, perhaps, forgetting what has been said above, you may be inclined to think that animals breathe while plants do not. This, however, is not true—plants find it just as necessary to breathe as animals do, but, as plants are not so energetic or active as animals, their breathing is so slight that care is required to observe it. You know that when you are running or playing football you have to breathe more deeply and more often than when you are resting. Now plants as a rule do not move about at all and therefore their need of breathing is small. Nevertheless, they do breathe.

We have found, therefore, that we cannot distinguish between plants and animals in this way. The next necessity for all living things, after breathing, is feeding. Can we find any difference between plants and animals in the way they feed? In Chapter II. you learnt that the main food of plants is a gas, namely the carbon dioxide present in the air. Any animal would find carbon dioxide a very poor sort of food: in fact, carbon dioxide is not merely useless as food for animals, but acts upon them as a poison.

Here, then, we have a very important difference between

plants and animals. *Plants* (or at least most of them) *can feed upon carbon dioxide, but animals can feed only upon plants or upon other animals.* This shows us, too, that plants must have appeared upon the earth before animals, for no animals could have existed until there were plants for them to eat.

Both plants and animals produce their young by means of eggs and sperm (pp. 181, 196). In the case of animals, sometimes the eggs are large, as in the case of birds, while in others they are so small that they cannot be seen except under the microscope. The distinction between the sexes, male and female, of animals is usually more clear than in the case of plants. But we shall study some animals that are both male and female, such as the earthworm and snail, and some that are neither, such as the amœba.

Summary.—Plants differ from animals (i) in their method of feeding; (ii) by the fact that animals are generally much more active than plants; and therefore (iii) animals breathe much more than plants, *but the breathing process is essentially the same in both.* Reproduction, in both plants and animals, is generally by means of eggs and sperm.

Plants

Anyone who has observed plant-life at all knows that most plants produce flowers, but that some, like ferns, moulds, seaweed and mushrooms, do not. Botanists therefore divide plants, for purposes of study, into *Flowering Plants* and *Flowerless Plants.* In this book we shall consider a typical flowering-plant, namely, the buttercup, and several types of flowerless plants.

The Buttercup.—The chief parts of an ordinary flowering-plant are: (i) the root, (ii) the stem and its leaves, (iii) the flower or flowers. Each of these parts has its own special work to do for the good of the plant as a whole. We shall

take the flower first, examine its structure and try to find out what it does.

FLOWER.—When we look at a buttercup, we see that each flower is borne on a stalk. This is called the *flower-stalk* and serves to hold the flower up in such a position that it can easily be seen. Later on we shall understand that this may mean a great deal to the plant.

FIG. 64. BUTTERCUP-PLANT

The flower itself consists of four different sets of parts. Beginning from the under side, we come first of all to a cup composed of a few (how many?) green *sepals*. These serve to protect the inner parts of the flower when in bud and also to prevent undesirable insects from crawling up into the flower and doing damage there. The sepals in some flowers are joined together, and in others they are not joined, but in either case the collection of sepals is called the *calyx*, which is only another word for "cup."

Just above the sepals is a circle of yellow *petals* (How many? Are they joined together or are they separate?). These form the *corolla*. They are very brightly coloured, and since the production of coloured substances means work for the plant, it seems very probable that the flower has *coloured* petals for a certain purpose and not merely accidentally. This point will be discussed later.

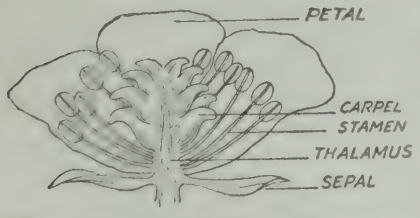


FIG. 65. SECTION OF FLOWER OF BUTTERCUP

Inside the corolla is a fairly large number of yellow bodies, each consisting of a "head" on a short stalk. These bodies are the stamens, and together they form what

is called the *andrœcium*—a word derived from the Greek, but since its meaning would give away a secret, let us leave it for the present. If you shake the stamens you will find that a yellow dust comes off from their heads or *anthers*. This dust is called *pollen*. If you have an opportunity, place some of this pollen in a saucer containing some water in which you have dissolved a little sugar, and then examine the tiny grains with a microscope or a powerful lens over a day or two.

Finally, in the centre of the flower there is a green mass made up of a number of *carpels*. This is the *pistil*, and, as you can easily see if you look at an old buttercup, the pistil later on gives rise to the *fruit*. The pistil is sometimes called the *gynœcium*.

Pollination.—If you were successful in your experiment with the pollen, you found that a tiny tube grew out of each grain. What happens to the pollen under ordinary circumstances? When you walk through a field of long grass, your shoes often become covered with pollen, and some of you may have noticed it upon the heads and backs of bees; while if you shake a hazel-bush in early spring a cloud of yellow pollen flies out of the catkins. It seems, therefore, as if the plants wanted to scatter the pollen broadcast.

Now look more carefully at the pistil of a flower—a primrose, for example. You will find that it consists of three parts, or, if the carpels forming the pistil are separate from one another (as in the buttercup), each carpel has three parts. The lower part is larger than the others, and is called the *ovary*, or seed-box; then there is a stalk, sometimes long and sometimes short, called the *style*; and at the top of the style there is a slightly larger part, often knob-shaped, called the *stigma*.

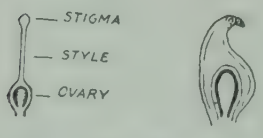


FIG. 66. PISTIL OF PRIMROSE AND CARPEL OF BUTTERCUP

Find the stigma of a flower and examine it carefully.

You will probably find that it is sticky and that it has some pollen-grains adhering to it. Have they got there by accident or is this the place which the plant (so to speak) *intends* they should reach?[1]

To answer this question, let us consider what the aims of a plant are likely to be. From the way in which weeds spread in an untended garden, we may reasonably suppose that plants are impelled to increase and multiply, and it is easy to see that a very good way of doing so is to produce a large number of seeds, each of which can grow into a new plant.

The flower is that part of the plant whose work it is to produce the seeds—the children of the plant. As in animals there are two sexes, male and female, and both are necessary for the production of young, so we find male and female flowers. Only it happens that in most cases each flower is *both* male *and* female, while animals are *either* male *or* female; the worm, however, as mentioned above, is like most flowers, since it is both male and female.

The female part of the flower is the pistil; hence the name *gynœcium*, which means "the house of the woman." The male part is the collection of stamens, i.e. the *andrœcium*, or "the house of the man." If you cut open the ovary of a young flower—say of a bluebell—you will find that inside it there are several very small green rounded bodies which clearly are going to be the seeds later on. But if you cut away the stamens of the flower and then keep it closely covered with a muslin bag, you will find that the ovules never develop into seeds.

Before the ovules of a plant can grow into seeds, pollen has to find its way to the stigma of the ovary. This explains why cutting off the stamens of a flower and then enclosing

[1] Of course, we do not think that the plant *consciously* intends anything at all, for it has no intelligence and probably no consciousness. But certain things happen *as if* the plant intended them to happen, and so we can use this form of expression as long as we understand that it is not to be taken literally.

it in a muslin bag prevents seed-formation, since pollen can no longer reach the stigma. When pollen-grains are caught by the stigma, they put out thin tubes in exactly the same way as they do in a sugar-solution, but in this case the tubes grow downwards through the style and at last reach the ovary. The part of what is left of the pollen-grain passes down through the tube and enters an ovule. This process is called *fertilisation*, because after it the plant is *fertile*, that is, it produces seeds. *Pollination* is the capturing of pollen by the stigma, so that the two words do not mean the same thing. After the ovules have been fertilised, they develop into seeds.

Since the ordinary flower is both male and female, that is, it produces both ovules and pollen, one would think that pollination occurs very easily; but there is an unexpected difficulty. In some cases pollen-grains are not capable of fertilising ovules of the same flower, and in very many cases the seeds produced from ovules fertilised by the pollen of the same flower are weak and unhealthy. To get the best seeds, ovules have to be fertilised by pollen from *other* plants of the same kind, and we find that many plants have the most ingenious devices for making sure that this *cross-pollination* shall occur.

One of the commonest plans is to attract bees, and arrange that they shall become covered with pollen during their visit. Then, when they fly to another flower, they bring to it pollen from the first. Moths, wasps and other insects are also made use of by flowers to effect cross-pollination. Such flowers are called "insect-loving"—a word which botanists with a weakness for the classics have converted into *entomophilous*.

In order to attract insects, most entomophilous flowers are brightly coloured: thus insects can easily see where they are. We realise now why plants go to the trouble of producing the brilliant colours of their petals; it is done with a purpose, as we suspected. But insects would not

continue their visits unless they found something in the flowers worth going for. Therefore entomophilous flowers, or at least the honest ones among them, make honey, which the insects eat or collect. If you strip off a buttercup-petal you will find at its base a little knob. This is the *nectary*, or place where the honey is formed.

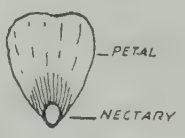


FIG. 67. NECTARY OF BUTTERCUP

One must, however, confess that certain flowers shamelessly deceive insects; thus the wild arum, or cuckoo-pint, produces a smell like decaying meat, which attracts flies. When the flies arrive, however, they find no meat, and are, in addition, trapped and imprisoned by the plant. In their attempts to escape, they crawl over anthers and stigmas indiscriminately and thus pollinate the plant.

Many plants have extremely ingenious devices for ensuring cross-pollination by insects. These cannot be described here, but those of you who have access to a library should borrow Darwin's book on the *Fertilisation of Orchids* and, after learning how cross-pollination is effected, get some wild orchids and examine the method for yourselves.

A good many flowers are pollinated by the wind, which blows the pollen from the male to the female flowers. These are said to be "wind-loving," or *anemophilous*, and since there is no need for them to attract or reward insects, they are generally greenish in colour and inconspicuous. Grasses and the hazel are examples of wind-pollinated plants.

Fruits and Seeds.—As has been mentioned above, the ovules after fertilisation develop into seeds. In order to fulfil their purpose, the seeds have to be distributed as widely as possible, in order (*a*) to spread the plant, and (*b*) to prevent the parent plant from becoming choked by young ones, as would happen if the seeds fell to the ground immediately below and started growing all round the parent.

When we eat young green peas, we realise how desirable for food the newly formed seeds may be, and that it is therefore necessary for the plant to protect them from the attacks of animals. They must also be protected from unfavourable weather, for they are generally very easily damaged and killed. Thus, as a rule, the walls of the ovary grow and increase in size with the seeds, and often form a hard shell around them. In other cases the walls are thick and fleshy, or they may consist of a hard inner one surrounded by a juicy outer one. Think of examples of these various kinds. The structure which contains the seeds is called the *fruit*; you should be careful not to mix up "seeds" with "fruits."

We have seen that the seeds must be (*a*) protected, and (*b*) dispersed or scattered. The hard walls of many fruits serve to protect the seeds inside, but what is the purpose of the fleshy coats of the plum, the peach, the apricot, etc.? Here we find that the plant, after having made use of insects, now calls to its aid the higher animals—even man. You all know how the merchant, in the *Arabian Nights*, having eaten his dates, threw the date-stones away, one unluckily killing a jinn's son. The merchant probably did not realise that he was doing just what the date-tree wanted him to do—scattering its seeds. In the same way birds and other animals carry off the juicy fruits of plants and drop the seeds often far away from their place of origin.

FIG. 68. DANDELION-FRUIT

Other fruits are dispersed by the wind, and have special apparatus attached to them for this purpose, e.g. the fruits of the dandelion. Still other fruits or seeds are shot away by an explosive mechanism, e.g. the fruits of the balsam readily shoot away their seeds on a slight touch. Poppy fruits have a circular slit towards the top, through this the seeds fall out when the plant is shaken and by the wind.

Germination.—Those seeds which are fortunate enough

to reach good soil sooner or later begin to grow. Let us examine a common seed and find out its various parts. Afterwards we can observe what happens when it begins to grow. The fruit of the broad bean is a pod containing about half a dozen seeds—the beans. Each seed is covered with a tough brown coat or *testa*. (What is this for?) At one end of the bean there is a black scar, the *hilum*, which marks the place where the bean was attached to the pod. On the narrow side of the seed there is a small triangular lump with its apex towards the hilum. If the bean has been soaked in water, and you squeeze it, you will find that a drop of water appears just below the point of the triangle. It has come through a very small hole in the testa, the *micropyle*, which you may be able to see if you look carefully.

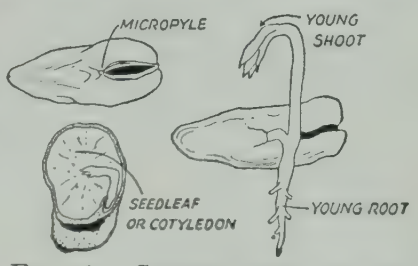


FIG. 69. GERMINATION OF THE BROAD BEAN

Now strip off the testa. Observe that the triangular lump in the testa was caused by a small white structure pointed at its free end. The rest of the seed can easily be split into flat halves if the blade of a penknife be inserted into the middle of the narrow side opposite to the triangle. You will then see that, lying between the flattened parts and connected to the triangular body, there is another small white structure.

When the seed begins to grow or *germinate* the triangle forces its way out through the micropyle, grows down into the soil, and forms the root. It is therefore called the *radicle*, or little root. Similarly, the other structure between the flattened parts grows, and after the testa has been sufficiently split by the growth of the root, it finds its way upwards through the soil to the air and light and becomes the shoot, bearing the leaves. In the seed it is called the *plumule*.

Then what is the purpose of the flattened parts which make up most of the seed? We shall see later that a plant cannot get food for itself unless it has green leaves; but the tiny plant in the seed must have food if it is to grow. Hence the parent plant starts it off with a good supply of food in the seed-leaves, or *cotyledons*, as the two flattened parts of the seed are called. When its shoot is above the ground and has developed little green leaves, it can take care of itself, but, to enable it to grow until that time, it has the food in the cotyledons. This food is largely made up of starch, as you can prove for yourselves by scraping a seed-leaf and then moistening its surface with a solution of iodine, which turns starch a very dark colour—almost black.

The seed, therefore, contains a miniature root and shoot, and two large white leaves stored with food, to keep the young plant alive until it can get food for itself. Some seeds, such as those of grasses, contain only one cotyledon, whilst those of pines and firs contain several. Most seeds, however, contain two.

If you compare a dry bean with a soaked one, you will notice that the dry one is not so large or so heavy; soaking a bean, in fact, makes it increase in size and in weight. This process, however, is not really growth, for a dead bean will swell in exactly the same way as a living one. It is, nevertheless, a preparation for growth. For a seed to germinate, the following conditions are necessary: (i) Water must be present; (ii) Air must be present; (iii) The temperature must be suitably high. If you think about it, you will see that these conditions are admirably fulfilled in spring-time, if the seed is buried in an open porous soil. For the soil would be moist, and the air would be free to penetrate its pores, while the warmth of the season would ensure that the third condition was fulfilled.

Roots.—If you examine the young roots of some seedlings (e.g. cress), you will notice that a short distance

above the tip of the root there is a band of fine white hairs (see Fig. 70). These are called *root-hairs*. When the seedlings are grown in soil the root-hairs cling very closely to the particles of soil, so that it is practically impossible to wash roots quite free from soil. The root-hairs suck up moisture from the soil and pass it on into the plant by way of the root. Dissolved in the moisture are many substances which are necessary to the life of the plant, although, as you already know, the plant obtains the greater portion of its food not from the soil but from the air.

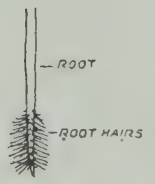


FIG. 70.
ROOT-HAIRS

Let us now consider the work of the root as a whole. It provides the plant, as we have just seen, with water and dissolved substances such as salt, phosphates and nitrates. It also anchors the plant in the soil, thus preventing it from being readily torn up by wind or birds or grazing animals. Besides this, however, plants often make their roots do all sorts of odd jobs. The ivy, for example, grows a lot of extra roots all up its stem and uses them for climbing and attaching itself to walls and trees. Roots such as these, which are not in their normal position on the plant, are called *adventitious roots*. Other plants use their roots as storehouses for food, stuffing them with starch and other substances to such an extent that they scarcely look like roots any longer. Plants of this kind are the turnip, the beetroot, the swede, the parsnip, the mangold-wurzel.

In addition to all these uses, the roots of a plant are occasionally used as a means of spreading the plant. Thus the lesser celandine forms a large number of small swollen roots which readily separate from one another. Each can then grow into a new celandine plant, so that the celandine often spreads with alarming rapidity, and if it gets into a garden may be a great nuisance.

Roots are classified according to their shape and the

position on the plant in which they occur. Those which consist of a mass of fine fibres are called *fibrous* roots; those having a large central portion from which finer ones branch off are called *taproots*; whilst those which are swollen with food-reserves are often called *root-tubers*. Roots which are developed directly from the radicle are true or "normal" roots. Those which are developed on the sides of stems, or on leaves, or even at the base of the stem but not from the radicle, are, as mentioned above, called *adventitious* roots, because they have simply "come."

Stems and Leaves (Shoots).—The stem of a plant serves chiefly to display the leaves and flowers. If you examine a plant, you will find that the leaves are arranged in such a way that they all receive as much light as possible, very few leaves even on a large tree being always in the shade. The leaves of the ivy growing on a wall are often arranged so carefully that, while there is scarcely any overlapping, the whole wall-space is covered with a "leaf-mosaic."

From this, and from the fact that plants grown in a window always grow towards the light, we may conclude that light is necessary to plants in some way. If plants are grown in the dark, they become yellowish and straggling: they look as if they had been vainly striving to reach the light. The reason for this we shall discuss farther on.

As in the case of roots, stems are often made to do work other than that for which they appear to have been originally intended. Many plants climb by means of their stems. (Can you think of any?) Some, again, store food in their stems, and since food is more likely to be safe under the ground than above it, food-storing stems are often condemned to live beneath the surface. Such underground stems are brownish in colour and look very much like roots. They are called *rhizomes*. They can easily be distinguished from roots by the fact that they generally have buds on them, while roots never bear buds. Very often,

too, a rhizome will turn green if it is brought back into the light. A good example of a rhizome is the potato, the "eyes" of which are the buds.

The work of leaves is not so obvious, so let us first examine their structure. Most leaves consist of a leaf-stalk, or *petiole*, and a leaf-blade, or *lamina*. Such leaves are said to be *petiolate*, whilst those which have no petiole, but *sit* directly on the stem, are called *sessile*. Leaves are sometimes made up of a number of small leaflets; in this

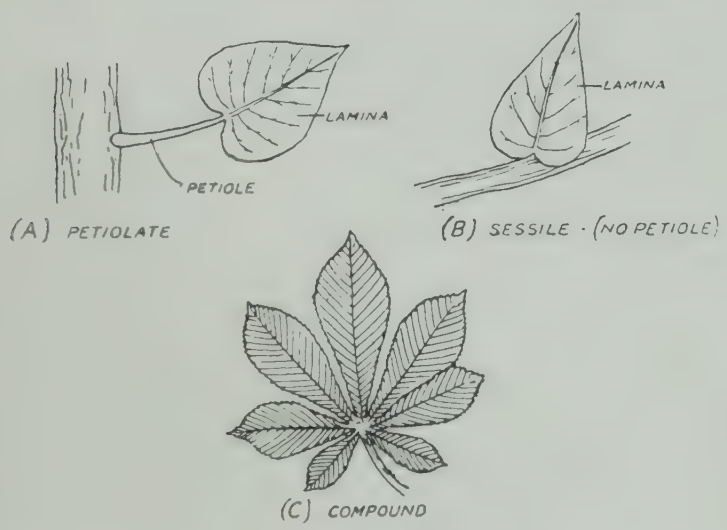


FIG. 71. LEAVES

case they are called *compound* leaves. Leaves are occasionally used for climbing (e.g. the pea, in which the leaves are converted into tendrils), and are sometimes converted into thorns and spines for protective purposes.

Everyone knows that the roots of a plant grow downwards, while the stems grow upwards. Is this by chance? You can easily satisfy yourself on this point by taking a young pea- or bean-seedling and planting it in moist sawdust or soil with its root pointing upwards. If you examine the plant after a few days, you will find that the root has turned round so that it is pointing downwards again. By

suitable adjustment, it is quite simple to make a root tie itself into a knot in this manner.

In the same way, you will find that the shoot will always twist itself round so that it grows upwards. In other words, the root of a plant is *attracted* towards the centre of the earth, while the shoot is *repelled* from it. This is an effect of *gravity* just as much as was the fall of Newton's apple, and we can prove it by growing plants on a wheel which is slowly turned round. Under these conditions the roots and shoots grow in quite haphazard directions.

Besides being affected by gravity, the roots and shoots of plants are directed in their growth by moisture and light also. Thus roots will always grow *towards* moisture and *away from* light, while shoots do just the opposite. Remember, too, how plants in a window always lean towards the light if they are left alone for a few days. The attraction of roots by water often leads to trouble in rural districts, where the roots of trees make for the water-pipes and drainage-pipes and block them up. It is a simple matter to show the attraction that water has for roots by germinating seedlings on the outer rim of a clay flower-pot kept moist from within. The first roots, growing over the edge of the pot, follow its outer sloping surface, instead of growing vertically downwards. The attraction of the water in this case is stronger than that of gravity. Air also has an attraction for most parts of a plant.

How Plants Live.—In order to live men and animals require water, other food, and air. Plants, as living things, require to feed, to absorb moisture, and to breathe, but they do so in a different way from that of animals. We have seen that they get water from the soil by means of the root-hairs, and that dissolved in the water are substances necessary for the life of the plant. Water is used by the plant partly for food and partly to keep it rigid. Note how quickly a plant wilts and droops if it is deprived of water.

Man does not—or at least should not—breathe through the organ he uses for eating—his mouth; but plants *use their leaves for both breathing and feeding*. If the under-surface of a leaf is looked at under a microscope, it is seen to be dotted with an enormous number of extremely tiny holes, very properly called "mouths"—only botanists despise the English word and use the Greek *stomata* (singular, *stoma*) instead.

The interior of the leaf is a network of passages (Fig. 72) through which gases can pass freely, and communication with the air can take place through the stomata. The essential part of breathing is the same in both plants and animals. It consists in taking in oxygen of the air, using a part of it, and sending the waste gases, chiefly carbon dioxide, back again into the air. This process goes on all over the bodies of all living things, but the actual in-going and out-going of the gases take place at the nose and mouth in animals and the stomata in plants.

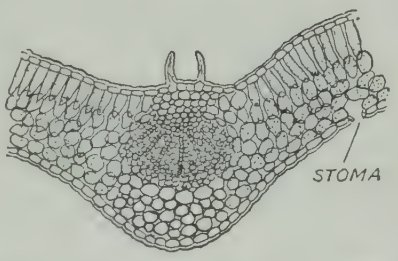


FIG. 72. SECTION OF A LEAF UNDER THE MICROSCOPE

Plants therefore breathe in exactly the same way as do animals, but since plants are not active beings, they do not require to breathe as much as animals do. For a long time it was thought that they did not breathe at all, or that if they did it was in an entirely different way.

The chief food of plants is the *carbon dioxide* present in the air. This gas gets taken in with the rest of the air through the stomata, and in the leaves the plant makes it combine with water to form *starch* or *sugar*, oxygen being left over as a waste product and sent back into the air. Now we know that to build a house from bricks requires work to be done, and to do work we need energy. In the same way the plant requires energy to build up starch

and sugar from carbon dioxide and water. Whence does this energy come? It cannot be produced by the food in the plant, *because it is used to make this food.*

If you refer to p. 172, you will remember that plants always seek the light as much as possible, and if you have heard of the attempts made by scientists in Egypt to get energy from sunlight, perhaps you will connect the two facts together and decide that the plant has solved the problem and uses the energy of sunlight for building up its food.

When light falls on an object, part is absorbed and part is reflected again (p. 148). Ordinary white light can be split up into light of many different colours (p. 148), so that if white light falls on an object which absorbs all the light except the red, the red will be reflected, and therefore the object will appear to be red in colour. Similarly, if an object is blue in daylight, it follows that it absorbs all the light-rays except the blue ones. Most plants are green in colour, or at least have green leaves. Hence we can infer that of the white daylight which falls on plants all is used by the plants except the green, which is not wanted and is therefore reflected. Plants thus obtain the energy necessary for starch-formation from the sunlight by means of the green colouring-matter of their leaves, which is called *chlorophyll*. This is a very complicated substance, the probable structure of which has been discovered only within the last few years. It absorbs all the rays of light except the green ones, and uses the energy so harnessed to convert the carbon dioxide and water into starch.

Thus we see that (i) plants cannot feed (i.e. build up starch and sugar) in the dark; (ii) they cannot make starch if they are kept in air from which the carbon dioxide has been removed. Plants which are not green, as, for example, mushrooms and toadstools, cannot feed on carbon dioxide, and have to resort to cannibalism!

In breathing, oxygen is taken in and carbon dioxide is

the waste product. In plants, however, *carbon dioxide is used for food* and oxygen is the waste product in this case. Thus two opposing processes are going on in the plant at the same time, and we shall be able to detect only the one which occurs to the greater extent. In the daytime this is the feeding process, since plants breathe but little. However, suppose we keep a plant in the dark. It will not be able to feed there, but will of course go on breathing. And, in fact, if this experiment be carried out, it will be found that the plant is using up oxygen and sending out carbon dioxide.

When the plant has made starch in its leaves, it wants to transport it to its store. But it cannot move solids, so it turns the starch into sugar, which dissolves in the water present. The solution of sugar is then made to flow in the desired direction, and when the sugar arrives at its destination it is turned back into starch.

A Few Plants of Bad Character.—It has been said that plants which are not green are usually cannibals: they live upon the dead bodies of other plants, and some of them even go so far as to prey upon living plants. But these do not represent the lowest stage of depravity to which plants may descend. There are a few plants which set out to lure insects into traps from which there is no escape, and there they kill them and use the dead bodies for food. These are the *insectivorous plants.*

Three insectivorous plants are found in England—the *sundew,* the *bladderwort* and the *butterwort* (Fig. 73 A, B and C). They all grow in damp places, such as the peat-moors near Glastonbury and elsewhere. The sundew has a number of leaves shaped something like salt-spoons, and on these leaves are many red tentacles. Each tentacle is tipped with a drop of a liquid which looks like dew, but which is really a very sticky gum. Flies see these drops glistening in the sunshine, and, imagining that they are honey, fly thither to investigate. When they get there they stick to the gum,

and while they are struggling the tentacles curl over and firmly imprison them. They finally die. The plant then digests them at leisure, after which the tentacles open again for fresh victims.

The bladderwort grows in marshy water. Under the surface of the water it produces a large number of small bladders, each of which has at one end a hole surrounded by fine bristles pointing inwards. Water-insects can crawl

FIG. 73. ENGLISH INSECTIVOROUS PLANTS

in through the hole very easily, but they cannot get out again, as the harder they push against the bristles the more effectively is the hole closed. They die at length and are digested. The butterwort lives on peat-moors and has shiny green leaves, the upper surface of which is sticky. When insects alight on a leaf they stick, and then the leaf curls over and holds them fast.

Many insectivorous plants are found in hot countries. The *pitcher-plant* (Fig. 74, A) forms large pitchers which have an attractive smell of decaying meat. They are very slippery on the inside, and at the bottom of them is water

in which the flies get drowned. The *Venus' fly-trap* of Carolina (Fig. 74, B) has leaves with triggers on them. When a fly happens to touch a trigger, the two halves of the leaf snap together and imprison him. It is even said that sometimes the fly is actually impaled upon one of the sharp hairs which form the triggers!

A B

FIG. 74. FOREIGN INSECTIVOROUS PLANTS

FLOWERLESS PLANTS

The Brown Seaweed.—Many of the commonest and most important plants do not produce flowers. Flowering-plants are the most highly developed, but flowerless plants are very interesting, as they appeared on the earth many thousands, and possibly millions, of years before those which produce flowers. We know that animals feed either on plants or on other animals, or sometimes on both. Plants, on the other hand, generally get their food from the carbon dioxide of the air. This shows us, as previously mentioned, that plants must have appeared on the earth before animals. It is probable that life began in the sea, and the brown sea-

weed, although not one of the earliest kinds of plants, has existed for untold millions of years, and probably flourished long before any plants at all were to be found on the land.

You must have noticed that the brown seaweed grows between high- and low-water marks. In this way it is sometimes covered by the tide and at others left dry. It is not surprising, therefore, to find (*a*) that the seaweed contains a large quantity of water, and that (*b*) it can survive being dried up and deprived of water for a very long time.

Primitive plants do not have their body divided into root, stem and leaves, as do the higher flowering-plants. This division of the plant-body into root, stem and leaves became necessary when plants took to living upon dry land, and we do not find it in water-plants except in the case of those which have taken to water again after having previously left it and become land-plants. A plant-body not divided into root, stem and leaves is called a *thallus*. The seaweed, then, belongs to the great group of the *Thallophyta* ("thallus-plants"), which includes also such plants as mushrooms and toadstools, moulds, and the green slime often found in running water.

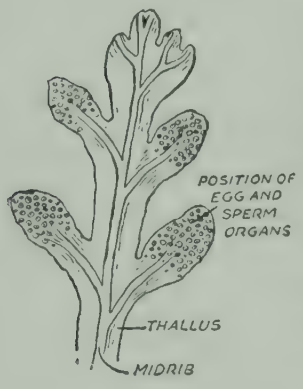


FIG. 75. THE BROWN SEAWEED

The thallus of the seaweed is flattened and branched. Towards the centre of the flattened part is a thickening, sometimes called the midrib. In the older parts of the thallus, towards the base, the flattened parts on either side of the midrib have worn away, so that the midrib now looks something like a stem. At the bottom the midrib is usually flattened out again into a disc or sucker, which holds the plant firmly to a rock. We do not call the disc, midrib and flattened parts "root, stem and leaves" respectively because, although they look something like them, they are not the same in structure and do not do

exactly the same things. Thus the oar of a boat is not called an arm because, although it looks something like an arm, it is different in structure and in what it does.

If you cut through the thallus, you will find that the interior contains much jelly, which helps to keep the plant moist when the tide has gone back. At intervals along the thallus are floats containing air. These keep the plant near the surface of the water, where there is more light and air. At the end of the branches of the thallus you may notice little yellow spots. These mark the position of the egg (roughly corresponding to the ovule) and sperm (roughly corresponding to the pollen) organs, which are used to produce new plants. These organs are too small to be seen with the naked eye, but they are shown in Fig. 76. As the plant has no flowers, it does not produce true seeds, but each egg gets fertilised by sperm, in the sea, and grows into a new seaweed-plant.

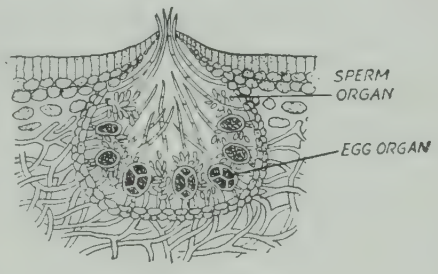


FIG. 76

The Mushroom. — The thallus-plants, or Thallophyta, are divided into two classes: the *Algæ* and the *Fungi*. The seaweed is an alga, and like all the algæ, it can get its own food from the carbon dioxide dissolved in the water. The fungi, on the other hand, at a very early period took to living upon other living or dead plants, or even upon animals, dead or alive. They therefore no longer needed the green colouring-matter chlorophyll (which is present in the seaweed although it is there mixed with a brown substance) by means of which other plants are able to build up food from carbon dioxide and water. We thus find that fungi are generally colourless plants.

In other respects fungi are closely related to algæ, and it is thought that, in fact, their ancestors *were* algæ at some very remote period. Fungi, however, have in many

ways fitted themselves for life upon land, although we can, in certain fungi, still see traces of a former existence in water.

The mushroom (Fig. 77) is a common fungus which grows in soil rich in the decaying remains of plants and animals. What we usually call the "mushroom" is, as a matter of fact, only a comparatively unimportant part of the mushroom-plant. The main part of the plant lives underground, embedded in the soil. It consists of an interlacing mass of extremely fine white threads called *hyphæ* (singular *hypha*). Together, these hyphæ form the *mycelium*, which is the name given to the thallus of a fungus.

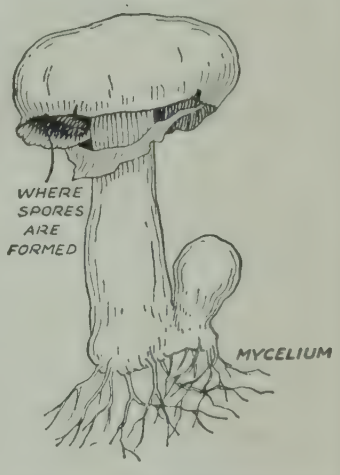


FIG. 77. THE MUSHROOM

Gardeners call lumps of earth full of these hyphæ "mushroom spawn," but this is quite incorrect. If anything can rightly be called "mushroom spawn," it is the brown dust which you can easily see by taking a mushroom-head and placing it on a sheet of white paper. If you now tap the "mushroom" gently and then lift it, you will find that the paper is covered with very small brown specks called *spores*. Each of these spores, if it is blown by the wind into suitable soil, is capable of growing into a new mushroom-plant. If you look at the under-surface of a "mushroom," you will see a number of thin plates (the so-called "gills") radiating out from the centre. It is on these thin plates that the spores are produced.

One peculiarity shown by most fungi, the mushroom included, is that of very rapid growth. Another is that the reserve food-material is not starch, as it is in green plants, but oil. Many fungi contain, in addition to oil, extremely poisonous substances, so that care must be taken not to eat poisonous varieties in mistake for mushrooms.

Moulds.—The bluish-green moulds which grow on jam, cheese, leather, and so on, are, like the mushroom, fungi. They are not able to build up their food from carbon dioxide and water, but live on material rich in food already. Plants which live on the dead remains or products of other plants, or of animals, are called *saprophytes*; those which prey upon living plants or animals are called *parasites*. Many moulds are saprophytes, but some are parasites, e.g. the fungus which causes the potato-disease. Others, again, may be either parasites or saprophytes, but these are less common.

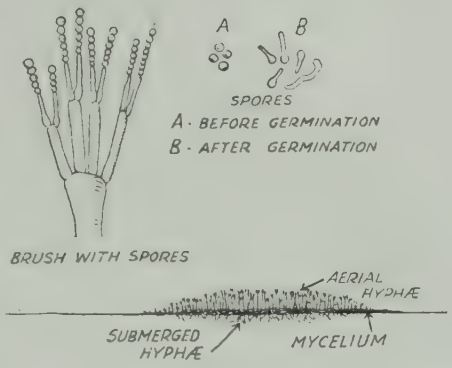


FIG. 78. PENICILLIUM

The commonest mould is *Penicillium* (Fig. 78). It is often found on old bread, stale cheese and jam. You will see that its thallus, or *mycelium*, consists of interlacing white hyphæ as delicate as the strands of a spider's web. Under the microscope (Fig. 79) each hypha appears as a thin tube containing a substance, called *protoplasm*, which resembles white of egg and in which drops of oil, the reserve food of the plant, can easily be seen.

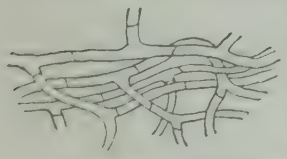


FIG. 79. HYPHÆ OF PENICILLIUM UNDER THE MICROSCOPE

The hyphæ spread rapidly over the surface of the object upon which the Penicillium is growing, and absorb the food-substances through their thin walls. Thus, as long as there is any food available, the fungus grows very quickly. After a time, however, the food begins to run short and the Penicillium then makes ready to spread to new pastures.

When this happens, the plant as a whole begins to look

bluish-green. This is because it produces enormous numbers of very small spores, the coats of which are bluish-green in colour. These spores are very light and are easily detached from the mycelium. They therefore get blown about by every puff of wind, and in fact they are always floating about in the air, so that if you expose a piece of bread to the air it is almost certain to "go mouldy" after a time.

You know that ordinary—green—plants can feed only in sunlight, because they need energy to build up starch from water and the carbon dioxide of the air. This energy they get from the sun. Fungi, however, use food which is already prepared, so they flourish quite as well in the dark as in the light—better, in fact, in many cases.

A mould very similar to Penicillium, but distinguished from it (among other ways) by the fact that its spores are quite blue, is *Eurotium*. You may find some Eurotium mixed with the Penicillium.

Yeast.—If you have ever seen a piece of yeast, you may have wondered what kind of thing it was. Yeast is a fungus with a very romantic history. Under the microscope, a piece of yeast is seen to consist of a great number of tiny rounded cells. Each of these is quite separate from the others, and is a complete yeast-plant in itself. When it is placed in a solution of sugar, it soon puts out a little knob, which gets bigger and is at last cut off and forms a new yeast-plant. This process is called "budding" (Fig. 80).

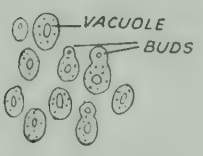


FIG. 80. YEAST-PLANTS UNDER THE MICROSCOPE, SHOWING BUDDING

To get yeast to grow properly there must be something else in the solution besides sugar: some food-substances in fact, for yeast does not *feed* on sugar. Yet it cannot grow without it. Then why does it need the sugar? Although the food we eat helps to keep us warm, yet in the winter we like to have another source of heat as well, and we enjoy a blazing fire. In the same way the yeast can get from its

food a *part* of the energy it requires for its active growth, but it gets a great deal more from the sugar by splitting it up into alcohol and carbon dioxide, a process which results in the setting free of much energy, which the yeast is able to use. This process is called *fermentation.*

Brewers therefore use a variety of yeast to make their beer alcoholic and at the same time effervescent from the carbon dioxide which comes off. Bakers use another variety of yeast in bread, because part of the starch in bread becomes changed into sugar, and the yeast permeates this. The carbon dioxide so produced makes the bread "rise" and gives it its characteristic porous nature. Alcohol is formed at the same time, and, although most of this is driven off by the heat, there is always some left in new bread. Pure alcohol is a colourless liquid which, if ignited, burns with a blue and very hot flame. It is extremely poisonous, and even when mixed with water can produce intoxication, i.e. "poisoning."

The fate of yeast, according to some botanists, is an awful warning to other fungi. If Penicillium is grown in a liquid containing an abundance of food and sugar—say in a solution of plum-juice sweetened with much sugar—it soon becomes demoralised. The hyphæ split up into rounded cells very similar to yeast-cells, and a riot of fermentation and budding goes on. If, however, the Penicillium is brought back to a sense of stern reality by being removed to pure cold water, it soon goes back to the mycelium form again. Yeast, however, it has been suggested, is a fungus like Penicillium which has got into the degenerate one-cell form, and has lost the password for return. It has proceeded so far on the downward path that it is unresponsive even to cold water!

Another class of fungi about which you have learnt something already is that of the *bacteria* (p. 53).

Mosses.—With the moss we have left the thallus-plants behind us. Mosses form one class of a group of plants

called the *Bryophyta*, of which liverworts (p. 187) form the other. They are more highly developed than the Thallophyta, but they must have existed on the earth for many millions of years. The commonest moss is called *Funaria* (Fig. 81). It is found growing on walls, banks, etc., and it is said that the first plant to appear on the site of a fire is almost always Funaria. It consists of a short brown stalk at the top of which is a rosette of thin green (or sometimes brownish) leaves. From the lower end of the stalk come off thin strands which do the work of roots, but as they are different from roots in some important respects, they are called not roots but *rhizoids* ("like a root").

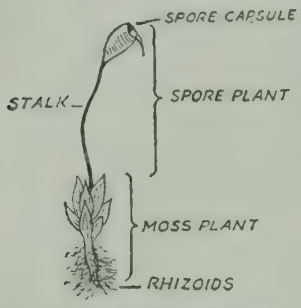


FIG. 81. A MOSS-PLANT. FUNARIA

Hidden in the rosette of leaves are the tiny structures which produce the eggs and sperm (Fig. 82 shows them as seen under the microscope). When an egg gets fertilised by the sperm, which swims to it through the moisture which covers the plant after rain, it does not grow directly into a new moss-plant. It divides and grows and sends up a long stalk with a knob or capsule at the end. You must all have seen these capsules growing on moss. When the capsule is ripe it contains a great many tiny brown particles, which are the "spores." These are to be blown about by the wind, so that the plant may spread. In order to make sure that the spores shall not fall out on a wet day—on which they would stick to the mother-plant or on the ground

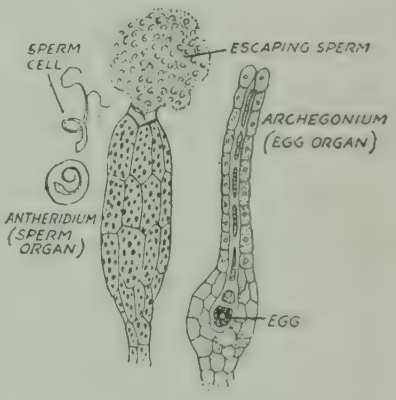


FIG. 82. EGGS AND SPERM OF FUNARIA

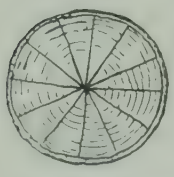
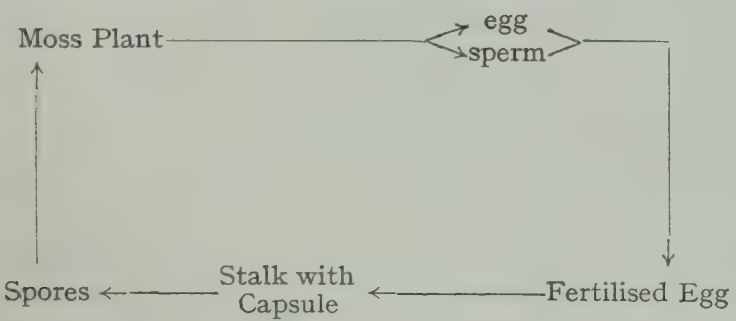


FIG. 83. END OF CAPSULE OF FUNARIA

close by, and therefore defeat the object for which they were produced—the end of the capsule is closed by sixteen teeth (Fig. 83), which close up together on wet days, but open wide on fine ones.

If the spores reach suitable ground, they grow each into a new moss-plant of the ordinary kind. Thus the life-history of the moss may be represented as follows:



The production of egg and sperm thus *alternates* with the production of spores, and we shall find this phenomenon more clearly marked in the other plants we have to study.

Liverworts.—Liverworts are so called because they are something like the lobes of the liver in shape, or perhaps because in olden days they were at one time used for curing, or attempting to cure, ailments of the liver. They are small green strap-shaped plants which grow in damp places, such as the walls of wells, the sides of ditches, and so on. Some may actually grow under water, though this is not usually the case.

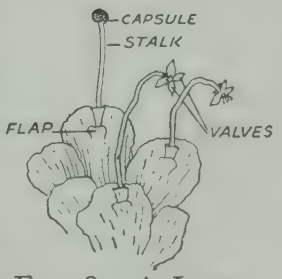


FIG. 84. A LIVERWORT. PELLIA

You will see that the plant-body has definite upper and lower surfaces. On the lower surface are several whitish rhizoids (p. 186), while on the upper you may see small half-moon ridges. Some varieties of liverworts do not have these ridges, e.g. *Pellia*, one of the commonest

(Fig. 84). The branches of the straps are forked at the ends, and between the two parts of a fork is a slightly swollen part partially covered by a thin green flap. It is on this swelling that the eggs are produced in special organs (see Fig. 85). The eggs, when ripe, are fertilised by sperm when, as in the case of the moss, the plant is covered by a film of moisture, from rain or dew. As with the moss, again, the fertilised egg does not grow directly into a new liverwort-plant, but into a different kind of plant consisting of a stalk and capsule. The stalk is usually white and the capsule black. When the spores inside the capsule are ripe, the latter splits open and allows the spores to escape. Mixed with the spores are some curious bodies called *elaters*. These rapidly alter their shape with variations in the moistness of the surrounding air, and in their wrigglings scatter the spores all around.

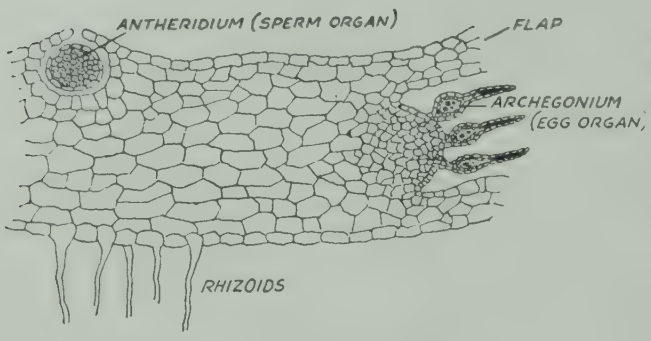


FIG. 85. ELATERS OF PELLIA

When the spores grow, each gives rise to a new liverwort of the ordinary kind. Hence, as in the case of the moss, the life-cycle is as follows: (i) The liverwort-plant forms eggs and sperm. (ii) The fertilised egg grows into a different sort of plant, consisting of a stalk and capsule. In both mosses and liverworts this new plant grows on the old one and is parasitic on it. (iii) This parasitic plant grows spores, which are scattered, and on germination grow into moss or liverwort-plants of the original kind.

There is thus an *Alternation of Generations*, as it is called —an egg- and sperm-producing plant alternating in the

course of the life-history with a spore-producing plant. In the other plants we shall consider, it will be found that this alternation has proceeded farther, to such an extent that the spore-producing plants now lead a separate and self-sufficient existence. Finally they become the more important of the two generations and the egg and sperm plants become less so. In the case of the moss and liverwort, however, the spore-producing generation does not lead a separate existence; it is parasitic upon the egg and sperm plant.

Horsetails.—The horsetails of to-day (see Fig. 86) are the few and insignificant survivors of what was once one of the most important classes of plants on the earth. In the days when our coal-measures were being formed, the forests consisted largely of immense horsetails, some of them as large as trees. But as flowering-plants were gradually evolved, they crowded out the horsetails until, at the present day, these are becoming rare and are never more than about three feet in height.

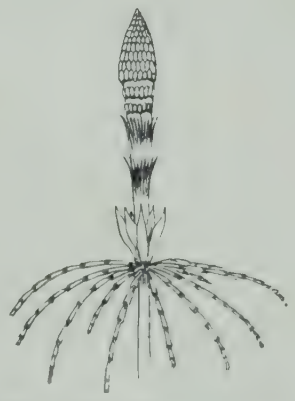


FIG. 86. EQUISETUM, THE HORSETAIL

Horsetails are flowerless plants belonging to a more highly developed class than those which we have studied hitherto. When you examine a horsetail-plant, you will find that certain of its stems end in a cone (Fig. 86). By cutting through a cone horizontally, you will be able to see its structure better. It contains a number of small chambers, each of which contains many spores.

If you think for a moment of the liverworts and mosses, you will see an important difference between them and the horsetails. For, in the case of the liverworts and mosses, the ordinary plant was the egg and sperm plant, while the spore plant was less imposing and was a parasite upon

the egg and sperm plant. In the horsetails, however, *the ordinary plant is the spore plant.*

When the spores are ripe they are shed. On germination they do not grow directly into new horsetail-plants, but form small plants rather like young liverworts. These are called *prothalli* (singular *prothallus*). On them are borne the eggs and sperm, and each egg, after fertilisation by sperm, grows into a horsetail of the usual kind. We see, therefore, that there is an Alternation of Generations in horsetails just as there is in liverworts and mosses. In the latter case, however, the more important of the two stages, as far as size is concerned, is the egg and sperm plant, while in the horsetails the more important is the spore plant.

The egg and sperm plants of the horsetails are very delicate and you will probably not be able to find any. Look, however, at the drawing of them given in the figure, and on the spore plant look for (*a*) the circles of small leaves; (*b*) the branches; (*c*) the spore chambers, and (*d*) the underground stem (*rhizome*) and roots.

Ferns.—In some ways ferns are not such highly developed flowerless plants as the horsetails, but they form a convenient subject with which to end our survey, as the Alternation of Generations is shown very well by them. A common fern is called the *Male Fern* (Fig. 87), not because there is another, "female," fern, or because it produces sperm, but because it was formerly used as a medicine especially for men.

FIG. 87. THE MALE FERN

You all know the underground stem, or rhizome, of the fern, with the brown fibrous adventitious (p. 171) roots upon it. From this rhizome arise the leaves, which in the young

state are curled up like an archbishop's crosier. The leaves, when fully grown, consist of a number of leaflets and each leaflet is further partially divided into a number of lobes, or *pinnules*.

Some of these leaves are used solely for breathing and feeding, but on the backs of others you will find some brown marks from which you can get brown dust by shaking. These brown marks are collections of spore chambers, and the brown particles of dust are the spores. Thus, as in the case of the horsetail, the ordinary fern-plant is the spore-plant stage of the life-cycle. When the spores are blown about and come to suitable ground (damp and shady), each grows into a thin heart-shaped plate about one-eighth to one-quarter of an inch across. This is called the prothallus, and is the egg and sperm plant of the fern. It bears the egg and sperm in special organs (Fig. 88) on its under-surface, and is attached to the ground by fibrous rhizoids. Each fertilised egg can grow into a new fern-plant of the ordinary type, but for fertilisation a film of moisture is necessary, as the sperm swims through the water to the egg. Prothalli, too, are very delicate structures, so that they are never found in dry places. Moreover, since the fern grows up from the fertilised egg, and this in turn is on the prothallus, ferns are usually found in damp and shady places. As a matter of fact, ferns are very hardy plants, and if they get a good start will live well in very dry and unfavourable situations. That they are not very often found there is mainly due to the fact that the prothalli must have damp and shade.

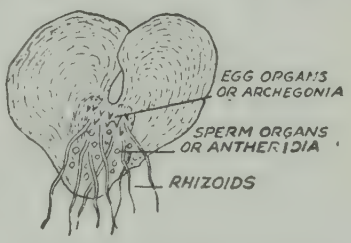
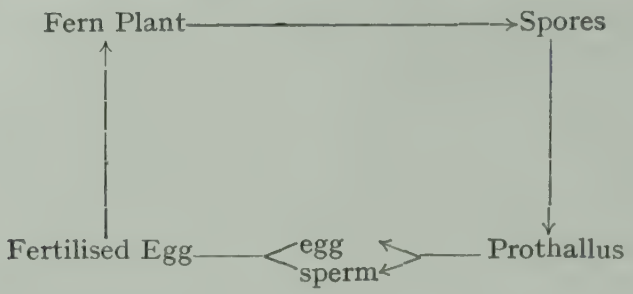


FIG. 88. PROTHALLUS OF FERN

Fern-prothalli are quite easy to find on damp and mossy banks underneath ferns, and they may often be found, in the country, growing on damp and shady walls..

The life-history of the fern is as follows. It should be compared with that of the moss given on p. 187.



Animals

The main differences between plants and animals have already been discussed. We shall therefore consider a few typical animals in the same sort of way as we have studied typical plants.

A Lowly Animal: the Amœba.—The amœba is a very small animal. To observe it properly a microscope is necessary, but if you are not fortunate enough to have this at your disposal, you will be able to see from Fig. 89 what the amœba is like.

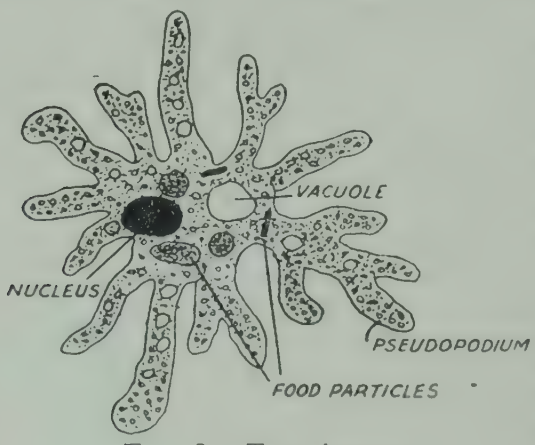


Fig. 89. The Amœba

Although the amœba is so small, it is of very great interest, for scientists believe that the very earliest animals to appear upon the earth were very similar to it. The "primordial protoplasmic globule" from which Pooh-Bah was proud to trace his descent must have been not unlike an amœba. The amœba, indeed, is just as much a relic of bygone ages as the elephant is at the other end of the scale of size. There

is this difference, however, that the amœba has come down to us from a period of the world many millions of years earlier than that in which the elephant appeared.

A very large amœba can just be seen by the naked eye as a tiny white speck. The animal lives in mud and water, and is present also in the soil, where it does a great deal of harm by devouring useful bacteria. Under the microscope it appears as a colourless mass of jelly or protoplasm, which slowly crawls about by putting out bulges called *pseudopodia*, or "false feet." Of course they are not really feet at all, but they serve one of the purposes of feet, namely, they enable the animal to move. The amœba has no eyes, no arms, limbs, brains, or any of the organs which a higher animal has. It breathes by taking in oxygen, which is dissolved in the water in which it lives, and sending out carbon dioxide. It has, however, no special organ set apart for breathing—it breathes all over its body.

If you look at an amœba under the microscope, or at the figure, you will be able to see several things inside the animal. One of these is a small round body rather darker than the rest of the jelly. This is called the *nucleus*, and is very important to the amœba. If the nucleus is cut out the animal soon dies. Besides the nucleus, you will very probably see, in the living animal, some greenish or brownish bodies. These are tiny plants which the amœba has eaten and is now digesting. The amœba has no mouth, but when it finds one of these small plants it flows round it and encloses it. This is how the amœba eats. When it has extracted from its food all the useful parts, it flows away from the remains.

Lastly you may see a small round hole in the amœba. This hole gets larger and larger and finally bursts, then starts again in the same place. It is filled with water, in which are dissolved various waste products which the animal wants to get rid of. When it bursts, this water is thrown out, and thus the waste products are removed.

As the amœba requires plenty of moisture, if the pond or muddy ground in which it is living dries up, it rolls itself into a ball and covers itself with a thick coat which protects it and prevents it from dying from drought. Then, when rain comes again, it bursts this coat, flows out, and leads its ordinary life once more.

Hydra.—Hydra is a small fresh-water animal. It is called *hydra* because if you cut it up into pieces each piece is able to grow into a full-sized hydra again, thus reminding us of the animal of the same name which the hero Hercules had some difficulty in killing.

The hydra is much larger than the amœba. You can easily see it without using a magnifying-glass, although to make out its structure it is necessary to use a good lens or a microscope. Specimens of hydra are often to be found on dead twigs and straws lying in the water of a pond. Some are green in colour, some are brown, and some are flesh-coloured or practically white. In shape the hydra is a hollow tube about one-eighth to one-quarter of an inch in length. At the bottom end the tube is closed, while at the other end it goes up to a blunt cone at the top of which is an opening called the mouth. Surrounding the base of the cone are about twelve to sixteen tentacles, which wave about in the water and by means of which the hydra can swim if necessary, although as a rule it prefers to stick on to a piece of wood or stem.

The hydra feeds on small water-insects, but does not object to small plants if they come its way. On its tentacles it has whole batteries of structures called *nematocysts* ("whip cells"). These are tiny bladders full of water and containing also a hollow thread coiled round inside (see Fig. 90, A and B). There is also a trigger at the top of the bladder. If a hapless water-flea happens to knock against the trigger, the bladder at once explodes and shoots out the thread with such force that the flea is stunned. It is then swept by the tentacles into the hydra's mouth. You will

know at once how the nematocyst works if you think of those impudent rubber balls made to resemble a face which shoots out its tongue when the ball is squeezed. Inside

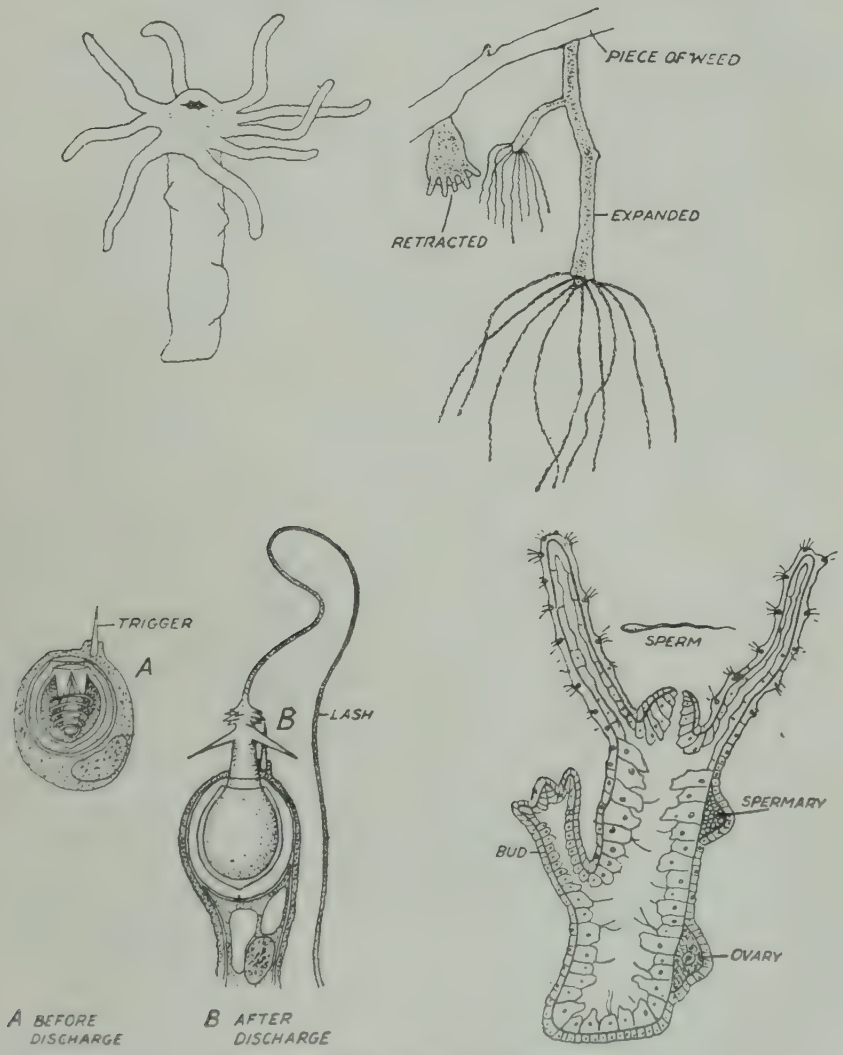


FIG. 90. THE HYDRA

the hydra the flea gets stuck to the inner wall, and is digested in much the same way as the plants are digested by the amœba. The undigested parts are then sent back through the "mouth."

When a hydra wants to move about the stick on which it lives, it does so in a peculiar way. It bends over until its tentacles touch the stick, to which they cling. The hydra then lets go with its other end and stands upside down. It then bends over once more till its lower end touches the stick, lets go with its tentacles, and stands upright again. This process is repeated until the hydra has gone as far as it wants to go. If it wishes to go farther afield, it swims through the water by waving its tentacles about.

Sometimes you will see little knobs on the side of a hydra. These get bigger and bigger and finally reveal themselves as young hydras, which break off at last and swim through the water until they find a suitable place to settle down. The formation of new hydras in this way is called "budding" (cf. the budding of yeast, p. 184). The hydra, however, produces young ones by means of eggs and sperm also. Each hydra is both male and female. The eggs are produced in the *ovary*, a little bag towards the lower end, and sperm (Fig. 90) in the *testis* or *spermary*, a similar bag higher up. When the eggs and sperm are ripe, the ovary and testis burst and the eggs and sperm meet in the water. Then a sperm joins with each egg, and the eggs, which are now *fertilised*, grow into new hydras.

The Tape-worm.—Zoologists call the tape-worm *Tænia*, which means a flat band. These names are given to it because of its shape. When it is fully grown, it may reach a length of as much as ten feet. It lives in the small intestine or bowel of human beings and very naturally makes them ill. It is made up of a rounded and rather enlarged end called the "head," which has hooks and suckers on it, and fixes itself on to the lining of the bowel. Attached to this "head" is a long body composed of a very large number of flat oblong chambers or segments. The part behind the head is narrow, and it is here that formation of new segments takes place. It follows that the oldest segments are those farthest from the "head."

Tænia is a parasite, and has no mouth or intestine since it does not need to digest food; it lives on the food which has already been prepared for digestion in the man or woman in whom it lives. Each segment, however, contains nerves and an ovary and testis, as well as little tubes which serve the same purpose as kidneys, that is, they get rid of waste matter dissolved in water.

When the eggs in the ovary are ripe, they get fertilised by sperm from the same or another segment, conveyed by means of a special tube. The fertilised eggs then become surrounded by reserve food-material or yolk, and by eggshells. By the time this process is finished, they have grown so much that they occupy practically the whole of the space in the segment, which then breaks off and passes out of the human body along with the fæces, or waste matter. Meanwhile the eggs have already begun to develop, and now contain young or *embryo* tape-worms very different in appearance from the fully-grown animal. They consist of roundish balls on which are six hooks (Fig. 91). Having once passed out of the human body, they grow no further unless they happen to be eaten by a pig. If this should occur, the embryos work their way through the wall of the pig's intestine until they come to a vein. There they get carried along in the current of blood and finally get stranded in a very small branch of the vein, generally in a muscle. They now grow, and at last become shaped like a bladder with a handle (Fig. 91, B), at the end of which is its "head" with its terrifying suckers and hooks.

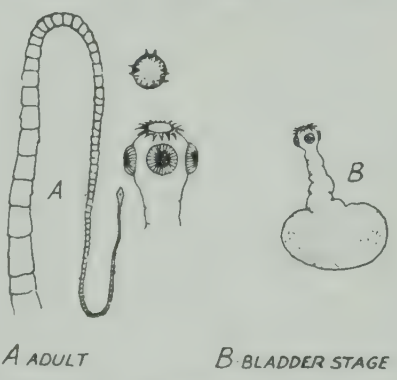


FIG. 91. TÆNIA, THE TAPE-WORM

Pigs containing these "bladder-worms" (which is only another name for the tape-worm at this stage of its life)

give, when killed, what is known as "measly pork." When measly pork is eaten by human beings, the meat is digested and the tape-worms which were in it are set free. They hook themselves on to the lining of the intestine, the bladder part disappears, the neck begins to grow, and so the adult stage is reached once more. It is because, in the East, pigs so often become infected with this and similar parasites, that they are regarded as unfit for human food and that Jews and Muslims are forbidden to eat pork and bacon.

It is interesting to note that Tænia is an example of a parasitic animal which must have *two* "hosts"—in this case man and the pig—if its life-cycle is to be completed.

The Earthworm.—The earthworm is one of the commonest of British animals and is found practically all over the country. It has been studied very closely by Darwin and other zoologists and a great deal is known about it and its habits. An earthworm is tubular in shape, tapering off towards the ends. The tail-end is rather flattened, and so may easily be distinguished from the head-end. It is supposed that the flattening of the tail enables the worm to get a good grip of its hole, and thus gives it an advantage in the unfortunate event of a tug-of-war with a bird!

The body of a worm is composed of numerous segments, about 150 in all. These are marked off from one another by grooves. Earthworms breathe through their skin, which is moist and slimy. They live in burrows not far below the surface of the earth, whence, in damp, warm weather, they partly emerge with only their flattened tails left in. At any sign of danger they retire to their holes immediately. The burrows themselves are made not only by the way in which the animal "worms its way" through the ground; there is another factor at work. Earthworms actually *eat* their way through soil. The soil appears to help their digestion, and passes out at the other end in a very fine state of division. This action helps to

keep the soil in good condition and to aerate it, so that the worm is really a friend of the gardener—especially as the only living plant it is at all likely to damage is the French bean, for the leaves of which it seems to have a great liking.

The worm moves by shortening or lengthening its body and at the same time putting out or drawing in very fine bristles, or *setæ* (singular *seta*), of which there are four pairs on each segment. If a worm wants to move forward, it sticks the setæ of the tail into the soil, draws in those of the front part and then stretches out to its full length.

Fig. 92. The Earthworm

As the setæ hold fast at the back, the worm reaches farther in front. It now fixes the front part by pushing out the setæ there, withdraws those in the tail, and draws the tail up. It then repeats the process until it has gone as far as desired. You can see the setæ on a worm if you look carefully, and you can easily feel them by allowing a worm to crawl over your hand.

The mouth is on the under-surface of the first segment. Worms feed on decaying vegetable-matter or even on fresh leaves; they are, however, particularly fond of animal-fat. They have no eyes or ears, and so can neither see nor hear in the usual way. To make up for this deficiency, they are very sensitive indeed to vibrations of the soil, and are alarmed, for example, at a heavy footstep. They can, too, tell the difference between dark and light, and they possess a keen sense of smell.

All worms are both male and female, but no worm fertilises its own eggs. When breeding, two worms lie side by side with their heads pointing in opposite directions, and sperm from each is passed into little chambers of the other. The worms then separate, and each forms a cocoon round the thickened ring, called the *elitellum*, which people

who know no better think is a scar marking recovery from bisection with a spade! The worm then wriggles backwards out of this cocoon, and as the openings of the ovaries pass through it, eggs are laid into the cocoon. Then come the openings of the little chambers containing the sperm from the other worm, and this sperm is now squeezed into the cocoon, where it fertilises the eggs. The worm then slips its head right out of the cocoon, the ends of which close up. As a rule, only one worm grows out of each cocoon, the other fertilised eggs serving as food to the lucky one.

The Snail.—Snails and slugs are called Molluscs. The garden-snail produces a shell which is always built up in such a way that, if you imagine yourself to be on the apex of it and to walk down around its grooves, you would always be turning towards your right hand (see Fig. 93).

FIG. 93. A SNAIL

During the winter, snails rest and withdraw completely into their shell. The opening of the shell they close with a wall made of a mixture of limestone, or chalk, and slime. This quickly hardens, but it allows air to pass through it slowly, so that the snail can still breathe. Naturally, when it is resting and thus doing no work, the snail requires to breathe only very little, so that the air which finds its way through the closing wall proves quite sufficient.

In the front end of the under-surface of the snail there is a hole through which slime is poured out. On this slime the snail moves along by means of muscles in the sole of the "foot" (Fig. 93). The animal, in fact, lays its own track as it proceeds. It moves, however, very slowly; so slowly that the expression "at a snail's pace" has become proverbial for slowness. How fast *do* snails move? Zoologists have had the patience to measure their rate, and have found that, on an average, they cover about one mile in

fifteen days! Compared with snails, slugs are fleet animals: they may easily do a mile in a week! An interesting fact about snails is that they appear to have a very good sense of locality. If you examine the tracks made by a snail during one of its nocturnal expeditions, you will almost always find that it has returned to the hole or corner whence it set out.

Snails feed on the young and sweet parts of plants; if you have a strawberry-bed you will know this quite well. On the roof of its mouth the snail has a hard jaw, while on the floor of the mouth there is a hard and horny band with about 15,000 teeth. In order to eat, the snail grinds up its food by rubbing these 15,000 teeth against the hard jaw. We can only hope that after a shameless exhibition of greed upon the strawberry-bed the snail will get toothache in each tooth.

The snail breathes by a kind of lung inside the shell. If you examine a snail, you will be able to see the opening to the lung just beneath the rim of the shell at the side. The snail's eyes are two in number. They are placed on the ends of the upper and larger pair of tentacles (Fig. 93), and can be withdrawn within the tentacles. The tentacle, when this happens, is turned inside out as one turns a sock. The process begins at the top, so that the eye is the first part to disappear within the shelter of the rest of the tentacle. Scientists have found that it is by means of smell that snails gain most of their knowledge of the world around them—this knowledge no doubt being chiefly concerned with the presence or absence of food. We are told that if a rotten apple is placed near some snails they will move towards it. Then, if the apple is moved, they at once alter their direction to follow it, while if it is held above them they will partly raise themselves from the ground to try to reach it. All snails are both male and female, like hydra and the earthworm.

Snails are injurious in the garden on account of their

voracious appetites. Anyone who has lupins in his garden knows that it is necessary to hold a snail-hunt every damp evening if he wants to preserve his flowers. Some kinds of snails, however, are used for food. This custom is more common on the Continent than in England, but it is not unknown even here. In Lawrence Hill and other parts of Bristol, for instance, snails may occasionally be seen exposed for sale on the barrows of street-hawkers; they are supposed by glass-blowers to improve the wind.

The Dogfish.—Animals are divided by man, for his convenience, into two big groups—those with a backbone and those without. The backbone is generally jointed, and each joint is called a *vertebra* (Latin, *joint*). Hence those animals which possess a backbone are called the *Vertebrata*, and those which do not are known as the *Invertebrata*. So far, the animals we have studied have all been invertebrates, which are less highly developed, in many ways, than the vertebrates. Other important invertebrate animals are insects, spiders, sea-urchins, jelly-fish and sponges. The vertebrate animals are divided into five groups, namely, the fishes, the amphibians (frogs, newts, toads), the reptiles (snakes, lizards, tortoises, etc.), the birds and the mammals (man, apes, cows, lions, horses, cats, dogs, rabbits, etc.). Mammals are so called because they suckle their young with milk from their *breasts*, the Latin word for which is *mammæ*. In this book we shall consider only the dogfish and the frog, although something will be said about the development of a bird, namely the chick.

The dogfish is found only in the sea, and very much resembles the shark, of which it may almost be called a small edition. It belongs to the same family as the shark and skate, and appeared in the course of the world's history much earlier than fish like the herring or cod. It is not large enough to be dangerous to man, but it plays great havoc with small fishes like the pilchard, which it pursues

in packs. It is also very fond of crabs and small shell-fish and consequently lives near the bottom of the sea, where it seeks its food by smell. Its flesh, though coarse, is sometimes eaten as food and is occasionally sold under the name of "rock salmon." The kinds of dogfish which are found around the British Isles are about two feet in length, but in other parts of the world larger kinds exist, some being as much as twelve feet in length.

You will notice at once that the shape of the dogfish is very suitable for an animal which lives in water. The whole body is narrow from side to side and smooth in outline. There is no neck, while the head is rather bluntly pointed. Thus the dogfish can cut through the water very easily and with very little resistance. It has two fins on its

FIG. 94. THE DOGFISH

back (*dorsal* fins), a tail-fin or *caudal* fin, two fins on the under-surface near the head (*pectoral* fins), two farther back (*pelvic* fins), and one, the *anal* fin, between the latter pair and the tail-fin. A fish does not swim by means of its fins. It swims by making strokes from side to side with the powerful muscles in its tail; the fins are used chiefly for steering and for ascending and descending in the water.

The mouth of the dogfish is not at the end, as it is in most fishes, but on the underside. The *anus*, or hole through which solid waste matter is expelled, is in a hollow between the pelvic fins. This hollow is called the *cloaca*, and into it open also the tubes conveying waste liquid matter from the kidneys, and the tubes from the ovaries in the female fish and from the testes (organs which produce sperm) in the male fish. The "nostrils" in front of the mouth have nothing to do with breathing (and therefore differ from

ours), but are concerned solely with smelling. The eyes are in the usual place, but have no movable eyelids. Behind them is an opening on each side called the *spiracle*, and at each side of the throat are five slit-like openings called the *gill-slits*. These are used in breathing.

The skin of the dogfish is peculiar. If it is stroked from before backwards it feels quite smooth, but if it is stroked in the opposite direction it is rough and spiny. This is because the skin bears numerous spines, called *dermal denticles* ("little teeth in the skin"), whose points are directed backwards. The denticles occur not only in the skin, but also in the mouth, where they serve as teeth (hence the name). These teeth are replaced as they are worn out, owing to the fact that the skin in which they occur grows forward, and thus brings the next row into position. We have thus the strange fact that the dogfish has teeth not only in its mouth, but all over its body as well!

Scattered over the snout of the dogfish, especially on the under-surface, are many small pores. These are the openings of long tubes filled with jelly. The tubes are supposed to enable the fish to tell whether it is deep in the water or near the top, since naturally the pressure in deep water is greater than that nearer the surface.

The dogfish breathes the oxygen dissolved in the water. The water passes in through the mouth, over the *gills* and out through the gill-slits. The gills consist of thin flaps filled with veins and having very thin walls. Thus the blood comes very close to the water and can take in oxygen and give up its waste carbon dioxide. The tube which leads from the mouth to the stomach (i.e. the *œsophagus*) is closed while the water is being forced out through the gill-slits, otherwise the fish's stomach and intestines would become filled with sea-water.

It is very simple to tell whether a dogfish is male or female. Look at the pelvic fins: in the male they are united behind the cloaca, and there are two stiff rods, called the

claspers, with which the male fish holds the female while the sperm is being transferred to fertilise the eggs. In this animal the eggs are fertilised before they are laid, inside the female. After they are fertilised by the sperm from the male, they are enclosed in an egg-case which has long curled elastic threads at its corners. They are then laid, and the threads get entangled in seaweed. Thus they are safely held while the young embryo dogfish develops within. The eggs are very large—about half an inch in diameter—and only two are laid at a time. Dogfish egg-cases with the young dogfish inside them can often be found in the seaweed round the shores.

The Frog.—The frog is the most highly developed animal that we shall study. It is a quadruped (i.e. it has four feet), and since it is equally at home in the water and on land it is called an *amphibian* (Greek *amphi*, both, and *bios*, life). Toads and newts are other amphibia. Like frogs, they live in water during their young days, but partly upon land when fully grown.

From an investigation of fossils, which are petrified remains of prehistoric plants and animals, scientists have come to the conclusion that at one time there were no vertebrate land-animals. Later on, however, some kinds of fish left the water, and, during a period which must have extended over a very long time, they gradually became adapted to life upon dry ground. To this day there are some fish (such as the Australian mudfish, found in the Burnett River, Queensland) which breathe by gills as a rule, but which possess lungs also and can use them when the dry weather comes. There are also certain tropical fish which live partly on land and partly in water. A species of perch which lives in India can even climb mangrove-trees by means of its fins.

The chief thing that strikes us about the adult frog is the fact that it has five-fingered hind-feet (in other words, it is a *penta-dactyl* animal). It is extremely difficult to

conceive how such a limb has been evolved from a fin, if indeed it did actually arise in this way. Fossils help us slightly, for scientists have discovered the remains of animals which, although more closely related to amphibia than to fishes, have retained certain fish-like characteristics.

Let us consider first of all the chief characteristics of the amphibious animals as a class. In the first place, they are naked-skinned animals, i.e. they do not have fur, feathers, scales or hair. Secondly, they all live in the water during their young days, and breathe then by means of gills, like fishes. Thirdly, the adult produces a relatively large number of eggs, in this respect differing from the dogfish, but resembling most other fish. Fourthly, it breathes by means of its lungs and also over the whole surface of its skin. In some amphibians, indeed, there are no lungs, and yet the animal can live quite happily in the air. This is accounted for by the fact that the skin is damp and that the gases in the air can therefore pass through it to the blood-vessels underneath.

The common frog of Great Britain is found all over the country in damp places during the summer. In the winter it sleeps in holes and other places where it is unlikely to be disturbed. In February and March it wakes up, and breeding takes place in water. As the female lays her eggs into the water the male pours his sperm over them, and the fertilised eggs ("spawn") then develop into small tadpoles which are somewhat fish-like in appearance.

FIG. 95. THE COMMON FROG

At the front end of the frog's body is the head, which is roughly triangular in shape and which bears the mouth, eyes and other organs. There is no neck, but to make up for this the frog's eyes protrude, so that it can see all round its body without moving its head. The eyes are large, but, unlike those of the dogfish, they have transparent

eyelids, the upper ones being movable and the lower immovable. The nostrils are small openings situated above the mouth at the front end of the head, and each one is continued backwards in the head by a passage which leads to the mouth—just as in the case of man. The ears are rather different in structure from ours, in that there is no "pinna," or outside fleshy portion. Just behind the eye is a little round patch, which is actually the ear-drum, or *tympanum*. If, in a dead frog, this is pierced with a needle or bristle, it will be found that this can be pushed through to the mouth. The object of the tube leading to the mouth is to equalise the pressure on each side of the ear-drum.

The body of the animal, called the *trunk*, consists of the back and the abdomen, the latter containing the various organs such as the heart, lungs, stomach and intestines, kidneys, and organs of reproduction (testes in the male frog, ovaries in the female). At the hind-end of the animal, just below the end of the back, will be noticed a small opening. This is the cloaca, and through it the reproductive bodies (eggs or sperm) and waste-food products are sent out.

The limbs have fingers, and each consists of three portions. However, the front feet have only four fingers each, whereas the hind ones have five and are also webbed. It is thought that, ages past, the ancestors of the frog had five-fingered front feet as well as five-fingered hind ones, and that is why zoologists call it a *penta*-dactyl animal. It is quite easy to distinguish between male and female frogs during the breeding season, for at this time the former have a rough dark-coloured swelling below the first finger on the fore-limbs. We shall see of what use this is later on.

The outside covering of the animal's body is the thick and tough protective skin. It is always moist and is richly supplied with small blood-vessels. In colour it is a mottled brown and green, and the frog can alter the colour of its

skin to correspond with that of its surroundings. In this way it is less likely to be seen by enemies.

How the Frog Lives.—You will have noticed that the mouth of the frog is very large and can be opened extraordinarily wide. Only the upper jaw bears teeth, and these are all alike. They are not fixed in sockets, but are joined directly to the surface of the bones of the jaw which bear them. When they are worn down they fall off and are replaced by new ones. On the floor of the mouth lies the tongue, which is fixed at its *front* end and points *backward* when not in use; to use it the frog has to turn it over. The frog feeds on worms, insects and other small animals, which it catches in a very interesting way. It flicks out its tongue with lightning rapidity, and in doing so wipes it against the roof of the mouth. Here the tongue picks up a gummy substance and becomes sticky, so that anything which it touches is caught: it behaves, in fact, as a kind of animated fly-paper.

The food so caught is swallowed whole, and it is amusing to note that the eyes help in the process. Unlike the eyes of most land-animals, the frog's eyes can be seen projecting into the roof of the mouth. As food is swallowed, the eyes are forced down and hence help to squeeze the food down the animal's throat. The teeth are not used for biting, but as hooks to prevent prey from escaping. They thus act in the same way as those of a boa-constrictor, though perhaps not nearly so well.

Full-grown frogs breathe by means of lungs, and they do so in a peculiar way. When we breathe, we expand our chest and air rushes into the lungs. Then we let the chest contract again and the air is forced out. The frog, however, takes a large mouthful of air, closes his nostrils and the way to his stomach, and then *swallows*, the air thus being *forced* into his lungs.

Frog's Eggs and Tadpoles.—About February or March the frogs begin to breed, an occurrence which can always

be recognised because the male frogs croak loudly at this time. The male clasps the female around the trunk with his fore-limbs, and remains in this position for two or three days. The pressure which he applies to the female no doubt assists in the laying of the eggs. The eggs are laid in water in large masses, and each is surrounded by a layer of jelly. As they are being laid the male frog sheds the sperm over them, and each egg becomes fertilised by one sperm. After a short time the jelly, which forms a protection for the developing egg and is later used as food, swells up and prevents any further sperm from entering. The masses of black eggs, each with its coat of transparent jelly, form conspicuous objects in ponds and ditches in the spring.

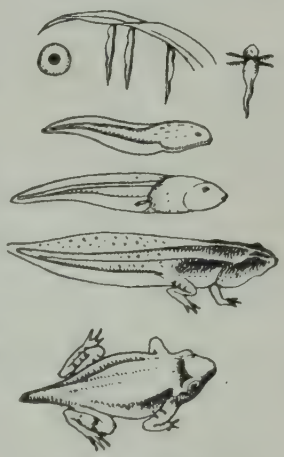


Fig. 96. The Development of the Frog

After about two weeks the egg hatches and out comes, not a frog, but a tadpole. It is quite small, being about half an inch in length. It has a tail, with ventral and dorsal fins (Fig. 96), a pair of feathery external gills, one on each side of the head, and a sucker, by means of which it can fasten itself on to weeds. It is blind and has no mouth. It spends its time either in swimming about or in clinging to waterweeds. After a few days the mouth appears, a second and a third pair of external gills arise behind the first pair, gill-slits like those of the dogfish are formed, and the eyes develop, so that the tadpole can now see. The mouth is quite small and is bounded by lips bearing horny jaws, by means of which the tadpole feeds upon the weeds, which form its chief food.

Meanwhile the external gills shrivel, and the gill-slits (of which there are four) develop internal gills (like those of the dogfish) upon their walls. At the same time a fold

of skin grows over the gill-slits on each side from before backwards, so that finally there is only one gill-opening, the slits themselves being hidden. This fold of skin is called the *operculum* (Latin, *a lid*), and should be compared with a similar structure in most fish, the herring and mackerel, for example. The sucker disappears, and at the same time small knobs make their appearance, one on either side at the base of the tail. These are the beginnings of the hind-legs. The fore-limbs have also begun to develop, but cannot be seen as they are covered by the opercula. After about eight weeks, up to which time the tadpole lives practically like a fresh-water fish, the gills begin to disappear and the lungs, which have been developing in the meantime, are nearly ready to take on their work. The legs increase in size, the fore-limbs push their way through the opercula, and the tail shrinks. The tadpole at this stage is truly amphibious, rising to the surface of the water every now and then to breathe air. At last the opening to the gills completely closes, and the animal now breathes by its lungs alone.

At the end of ten or twelve weeks from the time that the egg was laid the changes are complete. The tail and gills have entirely disappeared; the limbs are properly developed and the mouth, which has lost its horny jaws, is enlarged. The young frog, as it now is, comes out of the water and can lead its life upon land. It is, however, still fond of water and is always found in moist situations. When alarmed it will take to the water, in which it is capable of swimming with astonishing rapidity by means of its long and muscular hind-legs with their webbed toes.

In reptiles there is no stage corresponding to the tadpole. This is because the eggs of reptiles contain sufficient yolk or food-material for the young animal to develop directly, inside the egg, into its adult shape. The same thing is true of the eggs of birds. In frogs' eggs, however, there is very little yolk, and therefore the young animal has to fend for

itself before its development is complete. Reptiles and birds, that is, take greater precautions for the nourishment of their young than do amphibia; the latter produce a great number of eggs, only a few of which will reach the adult stage, whereas the former lay few eggs, most of which survive.

The Development of the Chick.—You may have wondered what goes on inside a hen's egg before the chicken is hatched out. It is a very wonderful process, but some of the chief changes that take place are quite easy to follow. The hen has one ovary, and the eggs when ripe pass into a tube called the *oviduct*. This leads to the outside, and in its opening sperm is placed by the cock. The thousands of tiny sperms then swim up through the moisture, lining the oviduct, until they reach the ripe eggs. Here each egg is fertilised by one sperm, and then starts on its journey to the outside world. It has in it a great store of food called yolk. Round this, special arrangements in the oviduct place first a covering of "white" and then a shell, after which the egg is laid. The yolk is slung inside the shell on twisted strands of a thicker "white," so that in whatever way the egg is rolled the embryo chick is always the right way up.

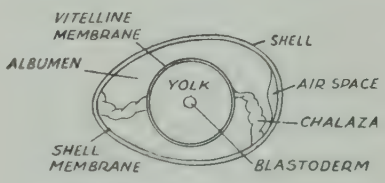


FIG. 97. THE STRUCTURE OF A HEN'S EGG

The fertilised egg (which, strictly speaking, is what we call the "yolk" only, the "white" and shell being merely coverings) begins to develop immediately after fertilisation. If you cut open an egg just after it has been laid, you will see a round white spot on the surface of the yolk. This is the young chick. When the eggs are laid, the hen sits on them to keep them at the proper temperature, and does not leave them—except for a few moments at a time, to get food—for three weeks, at the end of which the chicks hatch out. Contrivances called incubators have been made

which keep the eggs at the proper temperature if it is inconvenient to have hens sitting; they work very satisfactorily if carefully managed.

Soon the white spot mentioned above becomes pear-shaped, and down the middle of it appears a streak which marks the position of the future backbone. The embryo chick then gradually becomes, as it were, "pinched off" from the yolk, which is at first much the larger of the two. Then the brain, nerves and blood-vessels begin to appear, and we can see the heart as a folded tube into which the blood rushes and is then forced out again. The eyes develop very early, and are very large compared with the rest of the body at this stage. Later still we can recognise the beginnings of the wings and legs, and the whole chick grows in size until it occupies nearly the whole of the space inside the egg, the yolk and white having been used up as food. The embryo, of course, cannot *eat* them in the ordinary way, but they pass directly into its "stomach," when this is formed, by means of a short tube which is afterwards closed up.

At last the young chick has developed so far that it can look after itself. It pecks the shell with its beak and steps out to meet whatever fate is in store for it.

How Animals digest Food. — When we were studying plants, we found that green plants could feed upon a gas, namely the carbon dioxide of the air. Animals, however, cannot feed upon simple substances like this. They require more complex food, such as the bodies of plants or of other animals, or substances made from plants and animals. Men of science have found that a man requires five different classes of foodstuffs if he is to be properly nourished. These are: (i) water; (ii) salts, such as common salt; (iii) fats; (iv) substances called *carbohydrates*, of which sugar and starch are the commonest examples; and (v) substances called *proteins*, which contain a good deal of nitrogen and are found particularly in meat and cheese. In addition to

foodstuffs of all these kinds, it has recently been shown that, if health is to be maintained, a man must also be supplied with minute quantities of somewhat mysterious substances which are known as *vitamines*. If he fails to get these, he will begin to ail and will finally die, even though he has a plentiful supply of the five main classes of foodstuffs. There are three chief vitamines, one of the most important being found in fresh fruit and green vegetables. Since cooking is liable to destroy it, we should make a point of eating some of our vegetables or fruit uncooked. Another vitamine, which plays a great part in promoting growth and is therefore essential for young people, occurs in butter and in cod-liver oil. Exactly how vitamines work is not yet known, but sufficient research has been carried out upon them to show how important they are.

The processes by which the food we eat is *digested*, or made into a part of our body, are very complicated, but we can follow them in outline. For this purpose you should look at Fig. 98, which gives you some idea of the *alimentary canal*, or tube through which food passes in the body. The opening of this tube at one end is called the mouth. This communicates, by means of the *œsophagus*, with the stomach. From the stomach comes off a tube called the *small intestine*, and this in turn passes into the *large intestine*, which opens to the exterior at the *anus*.

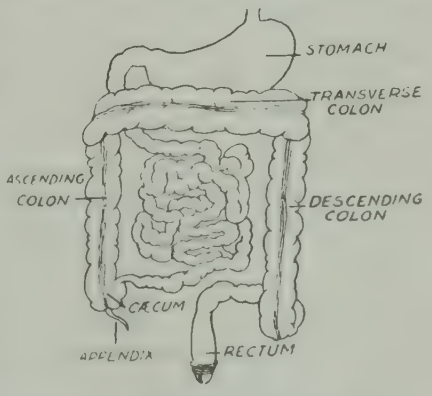


FIG. 98. THE HUMAN ALIMENTARY CANAL

The food which is taken into the mouth gets chewed up by the teeth and is also mixed with the watery liquid known as spittle or *saliva*. The saliva is produced in small

bags called the *salivary glands*, which are found below and in front of the ears and also between the bones which form the lower jaw. When we see a dainty dish, we say our "mouth waters." This is because the eye, having observed the attractive food, sends a message to the brain to inform it that something good is coming, and the brain then sends an order to the salivary glands to be ready with saliva for purposes of digestion. The saliva is mixed with the food and helps to make it moist. Its duties, however, do not stop here. Before food can be taken up into our body, it has to pass actually through the walls of the alimentary canal, a process which takes place chiefly in the small intestine. Now you can easily understand that no *solid* stuff can pass through a skin wall, and so the body first of all has to make all its food into a liquid state. This begins in the mouth. The saliva contains a substance called *ptyalin*, which has the power of converting starch, which will not dissolve in water, into sugar, which will. The ptyalin itself does not appear to be changed during this action, and in this respect is typical of a large class of substances in animals and plants. These substances are known as *enzymes* (Greek, *in yeast*), because the first one to be properly studied was found in yeast. We shall meet with more enzymes later on. They have an exceedingly complex structure, and chemists have not yet been able to explain to us exactly what they are or how they work.

In the mouth, therefore, the food is thoroughly chewed up, or "masticated"; it is also moistened by the saliva; and the ptyalin in the saliva begins to turn any starch in the food into sugar. You see, therefore, that it is very important not to "bolt" food. If the mouth is not given an opportunity of doing its work properly, food gets to the stomach in an unsuitable condition. The stomach has therefore to do work which it ought not to have to do, and *indigestion* is likely to result.

When the food in the mouth is ready, the tongue rolls

it up into a ball, and this is then swallowed. It passes down to the stomach through the *œsophagus*, which is the part of the alimentary canal connecting the mouth with the stomach. No digestion occurs in the œsophagus, which is rendered necessary merely by the fact that we have a neck, and therefore some arrangement is essential for conveying the food from the mouth, which is in the head, to the stomach, which is some distance away in the trunk.

When food arrives in the stomach it gradually gets heated up to blood-temperature (37·5° C. or 98·4° F.). It is also slowly churned round and round by movement of the stomach-muscles, and is mixed with a liquid, called the stomach-juices, which is produced in the walls of the stomach. This liquid contains hydrochloric acid and an enzyme called *pepsin*. The hydrochloric acid kills most of the germs which may be present in the food and also helps the work of the pepsin, which is to split up the proteins (p. 212) into simpler substances which are soluble in water. The ptyalin, however, is destroyed by hydrochloric acid, and so can no longer go on with its work upon the starch. At length all the food becomes converted into a kind of thick soupy liquid, and now is ready to pass on into the small intestine. This communicates with the stomach by means of a hole which is surrounded by a circular muscle, and can therefore be opened or closed as the body requires. We cannot consciously open or close it; the action is quite spontaneous. The muscle relaxes and the hole opens when the food is in a proper state, and not before.

In the first part of the small intestine the conversion of the food-substances into liquids, or into substances which will dissolve in water, is completed by other enzymes. Then the food is absorbed by the walls of the small intestine, passes into the blood-vessels which surround the walls, and is at last properly available to the body. Those parts of the food which cannot be absorbed pass on to the large intestine. Here a good deal of water is absorbed and

the residue or "fæces" thus becomes much thicker and relatively dry. Finally this waste matter is expelled through the anus.

You must remember, of course, that the above is only a brief general outline of the process of digestion in man. In other vertebrate animals the details of digestion may differ widely, for the alimentary canal of an animal is constructed in such a way that it can digest most readily that kind of food which the animal normally eats. For example, a *herbivorous* ("plant-eating") animal, such as the rabbit, has a part of its alimentary canal specially adapted for the digestion of *cellulose*, the chief substance in plants, and one which you will know in its common forms of paper and cotton-wool. Cattle, again, chew the cud, which enables the food to be mixed thoroughly with certain bacteria present in the stomach, and these help to prepare the cellulose for digestion. The snail possesses in its stomach an enzyme called *cytase*, which breaks up cellulose into soluble substances, and it has recently been shown that the ship-worm can actually digest the wood into which it bores! In certain "shell-fish" it is found that the saliva may contain as much as 45 per cent. of free acid, and this is used to dissolve the limestone shells of the smaller animals upon which the shell-fish feed. Lastly, it is interesting to know that blood-sucking animals have in their saliva a substance which prevents the blood of their victims from clotting, and they are thus enabled to enjoy their meal without haste. These few examples, then, serve to show us how varied the processes of digestion must be in different animals.

Getting rid of Waste Products.—We saw a few minutes ago that those parts of the food which are indigestible are expelled through the anus. During the life of an animal, however, waste products are constantly being produced throughout its body. An animal requires food not only to build up and maintain its body, but also as a source of

the energy it needs to live its life. Just as we burn coal in order to get the energy in a steam-engine, so the animal has part of its substances continually oxidised by the oxygen it breathes in. During this oxidation the required energy is set free, and certain waste products remain. The carbon, for example, in the oxidised substances is converted into carbon dioxide, which is sent out in the expired breath. The hydrogen, again, is very largely converted into water, some of which is exhaled as water vapour, as you can easily see by breathing against a piece of cold glass, which immediately becomes dimmed with moisture. A good deal more of the water is got rid of in the form of perspiration, but most of it passes through the kidneys and is excreted as *urine*. Meanwhile the nitrogen of the oxidised substances is not converted into free nitrogen gas, but is converted into a substance known as *urea*, which contains also some carbon, hydrogen and oxygen, and is expelled from the body dissolved in the water of the urine. The organs of the body whose special concern it is to look after the expulsion of water and urea are the kidneys.

The Preservation of Health.—The waste products formed by an animal are poisonous. In the large intestine, too, the indigestible food-matter is attacked by swarms of bacteria, and poisonous substances may be formed in this way. Hence, in order to preserve good health, it is essential to aid the body to get rid of all these poisons. Moreover, we have seen that vitamines are necessary to the preservation of health. Although, therefore, we have merely touched upon the fringe of the working of the human body, we can, nevertheless, draw some very important conclusions upon the question of health and disease.

In the first place, since oxygen is necessary to life, whereas carbon dioxide is a waste product, we can see that *fresh air* is essential. Stuffy rooms are a danger, not only because the percentage of carbon dioxide in the air

may become high in them, but also because other poisonous products may be given off in breath and because germs thrive better in a warm, close atmosphere than in cold, pure air. We can see, too, that *exercise* is of great value. It makes us breathe more deeply, and thus renews the oxygen and gets rid of the carbon dioxide right down in the bottom of our lungs: a thing which ordinary quiet breathing does not do. Exercise, again, makes our heart beat more quickly and thus sends the blood round our bodies at a greater rate; this helps to tone up the system and to get rid of waste products more efficiently. Finally, exercise stimulates our other internal organs to perform their work better and, in particular, it helps the large intestine to get rid of the fæces.

The importance of eating fresh green vegetables, in order to get vitamines, has already been mentioned. In this connection, however, it is interesting to note that *sunlight* has, in many respects, the power of acting in the same kind of way as the vitamines themselves, so that a sunny day is really a very valuable contribution to the health of the nation. Children brought up in smoky cities, where the sun is rarely seen for long at a time, are likely to be less robust and healthy than those in the country. Sunshine, too, has of course the effect of making us feel cheerful, and the more cheerful we feel the more healthy we shall probably be. It has, indeed, been conclusively shown that fear and anger and grief do actually produce poisons in the body which help to lower its tone. And in addition we must not forget that sunlight is a very powerful germ-killer.

Cleanliness of body is another great aid to health. A great quantity of poisonous waste matter is expelled by the body through the pores in the skin (perspiration, etc.). If we do not keep our skin clean, the pores become clogged and the waste matter therefore remains in our body. Many diseases, again, are caused by bacteria. The cleaner

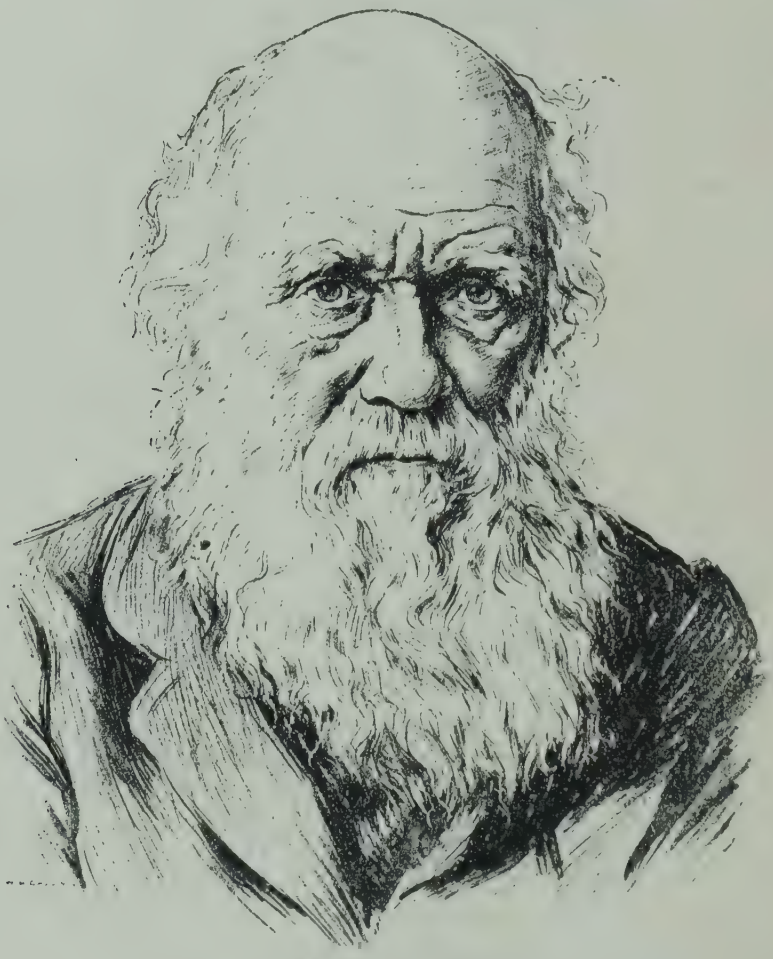
we keep ourselves the less chance we shall give these bacteria of gaining an entrance. This is particularly important in the case of the teeth. If the teeth are regularly and carefully brushed, the bacteria which lodge on them get swept away before they have time to get firmly established, and hence decay of the teeth is prevented. Since, if our teeth are decayed, we cannot masticate our food properly, and thus may soon suffer from indigestion, it is clearly of great importance to take all the steps we can to prevent decay; this all the more since many far more serious diseases may be produced by long-continued indigestion.

Evolution.—A country walk, or a visit to a museum of natural history, will impress upon us that the number of different kinds of plants and animals is very large. There are, in the British Isles alone, thousands and thousands of different sorts of plants and animals, and we may have asked ourselves how all these various kinds of beings have come to exist.

We can begin to get an answer to this question by examining fossil plants and animals which have been dug up from the earth in coal, rocks, and so on. These fossils are not like the animals and plants of to-day, and the older they are the greater does the dissimilarity generally become. Moreover, the very oldest of them are, as a rule, much simpler in structure than those which now live upon the earth.

Charles Darwin (1809–82) thought over these and many similar facts for a long time, and at last, in 1859, he published a book, called *The Origin of Species*, in which he offered an explanation of the problem. Shortly, this explanation was as follows: The kinds of plants and animals which grow now have not existed unchanged from the beginning of life upon the earth. They have descended from ancestors which become less and less like them the farther back in time we go. This is proved by a study of fossils. Our present flowering-plants, for example, are—

we might almost say—a modern product and represent the latest improvements which Nature has made in the plant-kingdom. Thus, according to this theory, there has been a slow and gradual change of plants and animals



CHARLES DARWIN

throughout the millions upon millions of years which have elapsed since life began, each new variety being a little better than the one which went before it, as far as the powers to live and multiply are concerned.

You know, from the enormous number of seeds produced

by a great many plants, that, if there were no obstacle to its increase, a single race might very quickly overrun the whole earth. As a matter of fact, the number of individuals of each kind remains in most cases about the same from year to year. What, then, are the causes which prevent a particular kind of plant or animal from spreading to such an extent? The answer is the *struggle for existence*, which results in the *survival of the fittest*. This process Darwin called "Natural Selection." One plant, for instance, has to compete with another for room, food and light. In this struggle the strongest, or those which can make most use of their surroundings, win and the weaker die out. Among animals this struggle for life is keen and cruel, and it is no less so among plants. It is bitterest between those of the same kind. Different kinds of plants, for example, make different demands upon the soil and the sunlight, but plants of the same kind have the same needs and hence the struggle between these is fiercest.

Now, if an individual plant or animal happens to possess a characteristic which the others have not, or if it possesses a characteristic in a higher degree than its neighbours, and if this characteristic gives its possessor an advantage in the struggle for existence, this individual is more likely to survive than those which are competing with it. Let us illustrate this by an example. Suppose that a group of plants is growing in soil where the water-supply is not good. If one of those plants has larger and more branched roots than the rest, it will be able to take a larger share of the water and may therefore live on when the others are killed by drought. If, in addition to this, the advantageous characteristic can be handed on by the plant to its offspring, there will form a slightly different *kind* of plant, distinguished from the others by its larger and more efficient roots, and so much the better adapted for the struggle for existence. It was this way that Darwin explained the origin of new kinds of plants and animals.

This explanation thus depends upon the truth of the following statements:

(i) *Variation.* Though offspring are like their parents, no two individuals, though born of the same parents, are ever *quite* alike. Each shows peculiarities, and sometimes this variation is great.

(ii) *Survival of the Fittest.* In the struggle for existence the fittest survive and the weak are crushed out by the strong. In the plant and animal worlds might is right.

(iii) *Fitting in with the surroundings*, or, as it is generally called, *Adaptation to Environment.* In the case of plants, for instance, the land upon which they grow has been in ages past subject to many changes—changes of climate, changes of soil, changes of temperature and physical condition. Plants which did not change so as to produce characters enabling them to fit in with these changes naturally died out. Those that did, lived and flourished. A race flourishes when it fits in with its surroundings, and is most secure when its adaptation to the surroundings is most complete. If it is crushed out of its existence by competitors, this means that the competing races are better fitted to the new conditions than it is itself. Success in any given conditions is reached by different plants in different ways. This must be so, for in the same place, such as a hedge, we find many different sorts of plants. These often differ widely in form, but are able to live together under the same conditions. Each has solved the problem of adaptation in its own way.

We have then, finally, to explain in what way a new character, such as the large root given as an example above, may be acquired. Darwin believed that a specific character—that is, a character which distinguishes one race or species from others—has been produced by the accumulation, from generation to generation, of very small variations. There are many objections to this theory, and it is not generally accepted to-day. Another theory

is that *large* variations appear *suddenly*; that a given species remains practically constant for many generations and then suddenly begins to produce offspring unlike itself in certain noticeable respects. Of these variations some may be useful and some not, but each reappears in the respective offspring. The fate of these new forms is then decided by the struggle for existence. This theory has received a good deal of support, but there is a lot to be said against it. In short, although the *fact* of evolution, that is, the fact that all plants and animals appear to have been derived from common ancestors, is accepted by all intelligent men, and although the discovery of this fact will ensure Darwin's undying fame, his suggestion of the *way* in which this evolution takes place is doubtful. We must wait for more facts before we can decide.

The Work of Mendel.—A good deal of light has been thrown upon the problem of variations in plants and animals, and even in man, by the work of an Austrian monk named Gregor Mendel, Abbot of Brünn (1822–92). Experimenting upon sweet-peas, Mendel found that, when dwarf sweet-peas were fertilised with pollen from tall sweet-pea plants, and succeeding generations bred from the seeds so produced, both tall and dwarf sweet-peas were produced in definite proportions. Similar results were obtained in experiments upon fowls, in which it was noticed that the proportions of certain shapes of combs in successive generations were definite. Investigations upon these lines have enabled biologists to understand a great deal about "heredity," or why offspring resemble their parents in most respects but differ from them in others, and no doubt in the future the way in which evolution has occurred will be satisfactorily explained.

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CHAPTER VIII

CONCLUSION

We have now come to the end of our rapid survey of some of the wonders which science reveals to us, and it is time to pause and take stock of the country traversed. We have seen how the spirit of inquiry has inspired men, even from earliest times, to ask questions of Nature, and to ponder over her replies. In ancient times comparatively few facts were known, and men had not then developed those methods of investigation which in later days proved to be of so much use. As a matter of course, therefore, progress at first was very slow, and though much useful knowledge was acquired, it was very frequently contaminated with grave errors and childish superstition. Nevertheless, we must not laugh at early scientists or hold their work in contempt, for our own scientific knowledge is based on the work of our predecessors, and as far as superstition is concerned we are very little better than they. It is not only in remote country districts that people bow to the new moon and turn their money over, in order to get luck; many an Englishman who knows and appreciates the latest achievements of science nevertheless takes particular care not to walk under a ladder; and the number of people who refuse to make one of a party of thirteen is in itself sufficient to show us that superstition is by no means dead even in this twentieth century.

As true appreciation of scientific thought and method grows, however, we may hope that men will gradually become wiser. Yet wisdom alone, although it places untold power and unlimited capabilities for good and evil in the hands of mankind, is not sufficient. A man with great

knowledge is not necessarily a good man, and one of the chief benefits we obtain from a study of science is that it teaches us to value beauty, truth and goodness as well. All three of these are necessary, and equally so, but in science it is Truth which is of the most paramount importance. Science shows us beauty and makes us love it; the spirit of science is a living example of the value she places upon goodness. Truth, however, and an unfaltering honesty form the very life-blood of science, and whereas a study of the classics or of history enables us to understand better the causes and results of events in which human feelings play the chief part, one of the principal aims of science is to teach us that, in dealing with Nature and wresting her secrets from her, we must suppress our own desires and proceed upon our way with an absolutely unbiassed mind. When he discovers facts which do not fit in with his own ideas, the scientist—however precious those ideas of his may be to him—does not attempt to hide the facts or to gloss over them. If, after further investigation, the facts are found to be true, he steadfastly refuses to blind himself to them, and he abandons his opinions in favour of fresh ones which will agree with the facts. It is, in short, an invariable rule in science that theories and ideas have to be fitted in with the facts; there can be no tampering with the facts in order to make them fit in with a theory.

Especially, therefore, to those of you who will study science only at school is a proper understanding of the spirit of science necessary. You will, perhaps, have gained some idea of it already from the preceding pages, but you will find a great deal more about it, expressed in very charming language, in Sir Richard Gregory's book called *Discovery*. There you will be able to see the aims which inspired the great men of science and may gain a knowledge of the various and manifold ways in which science is helping the world.

Science and the Future.—Although science has already told us so much, we do not suppose that we yet know more than a very little of all there is to be known. If, in the short space of a hundred years, during which science has grown so fast, it has been able to change completely the conditions of life upon the earth, what may it not do in another thousand years? We do not know and we can scarcely guess. We do know, however, that with each succeeding year man's power over Nature rapidly increases. Whither it is all leading, no man can say. Recently several men have written books to say what they imagine will be the effect of science upon the world in the future. Some of them believe that mankind will be made very much happier, while others, who have been grieved at the use made of scientific knowledge in the European War, think that the reverse is more likely to be true. The gloomy predictions of the latter men, however, will certainly not be verified if men will only use the gifts of science in the spirit which inspires science itself. The possibilities of science for good and for evil, as has been said before, are practically infinite. But look back over the work that you have done and over the books which you have read, and see if you can find one instance in which a man of science has used his discoveries in order to harm the human race. You will not find one. If everyone acquires a knowledge of science, and the aims and methods of scientific investigation, it is far more probable that the rosiest dreams of the optimists will seem pale beside the reality, for with a greater devotion to Truth it is hard to see how men can fail to be better than they were before.

On the purely practical side we have only to think, for example, how science has enabled us to conquer many diseases, to understand how health may be improved in the future. We saw how malaria has, in many parts of the world, been absolutely exterminated; the plague, which used to kill hundreds of thousands of people every year,

has been got under control and we may hope that soon it will be wiped out altogether. The causes of other diseases are being discovered, and when their causes are found it is often a simple task to show how they may be prevented. Improved means of communication, again, have rendered our life much more comfortable and interesting, and perhaps in the future the whole world will be brought within an hour or two's journey from our doors.

It is, however, an idle occupation to speculate upon the uncertain future. What we can be certain of is, that, if the bounties of science are used as men of science earnestly desire that they should be, the earth will be a better place for every man upon it.

And if you yourselves one day take up the study of science as your life's work, remember Charles Kingsley's description of students of science. They are, he says, "good men, honest men, accurate men, righteous men, patient men, self-restraining men, fair men, modest men. Men who are aware of their own vast ignorance compared with the vast amount that there is to be learned in such a universe as this. Men who are accustomed to look at both sides of a question; who, instead of making up their minds in haste, like bigots and fanatics, wait, like wise men, for more facts, and more thought about the facts."

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